WindSat

Systems Requirements Review (SRR)

December 16-17, 1997

Agenda (1 of 4)

Day 1	Presenter	Time	Tab #
• Mission Overview and Requirements Analysis			
• Mission Overview	Hoskins	0900	1
• Spacecraft Bus Status/Secondary Experiment	Spencer	0930	2
• WindSat Science Mission Requirements	Gaiser	0945	3
• Mission Operations	Barock	1030	4
• Mission Constraints			
• Systems Environments Analysis and Trades	Koss	1100	5
• Orbit Selection	Kelm	1130	6
• Lunch		1145	
• Payload Conceptual Design & Requirements Review	Gutwein	1245	7

Agenda (2 of 4)

Day 1	Presenter	Time	Tab #
• **Payload Electronics**			
• Antenna Subsystem	Lippencott with Bartlett, Gutwein	1400	8
• Payload Warm/Cold Calibration Subsystem	Gaiser	1515	9
• Payload Receiver Subsystem	Xavier	1545	10
• Payload Data Handling	Nicholson	1645	11
Day 2			
• Communications Subsystem	Lyon	0830	12
• Bulk Storage	Plourde	0845	13
• Electrical Power Subsystem	Baker/Plourde	0900	14
• Mission Software CSCIs	Gonyea	0915	15

Agenda (3 of 4)

Day 2	Presenter	Time	Tab #
• Payload Mechanical	Purdy	0945	16
• Attitude Control System	Mook	1015	17
• Structures	Cottle	1115	18
• Lunch		1200	
• Mechanisms	Koss	1300	19
• Thermal Control Subsystem	Kim	1330	20
• Integration and Test	Penn/Purdy	1400	21

Agenda (4 of 4)

	Presenter	Time	Tab #
• Reliability and Safety	Spencer	1430	22
• Calibration/Validation	Poe	1445	23
• Technology Transfer	Gaiser	1515	24
• Top Level Spacecraft Interface	Spencer	1530	25
• Program Risk Analysis Wrapup	Hoskins/Spencer	1545	26
• Action Item Review	Hoskins	1600	

Mission Overview

WindSat Mission Overview

Characteristics/Description:

- Measures Ocean Surface Wind Speed, Wind Direction, Using Polarimetric Radiometer on a Modified Satellite Bus, Launched Into a 850 km 55° Orbit by the First Evolved Expendable Launch Vehicle (EELV)
- 3 Year Design Lifetime

Capability/Improvements:

- Measure Ocean Surface Wind Direction (Non-Precipitating Conditions)
- 3 X Improvement in Horizontal Resolution (SSMI-37Ghz)
- Secondary Measurements
  - Sea Surface Temperature, Soil Moisture, Rain Rate, Ice, and Snow Characteristics

Special Features:

- Demonstrate Polarimetric Radiometry
- Risk Reduction for National Polar - Orbiting Operational Environmental Satellite System (NPOESS)
- Space Test Program Satellite Bus
- Test Article for EELV
- Sensor to Shooter Direct Data Read-Out
- Highly Leveraged Execution Plan

What Is the Need?

- **<u>This Program Is Needed Operationally Because:</u>**
  - **Provides Navy Unique / Mission Critical Sensors and Proof of Concept for Use on NPOESS Satellites**
    - **Current Emphasis Is on Real Time Ocean Surface Wind Speed and Direction**
  - **Improves Battlespace Awareness**
    - **Project and Sustain a Forward Presence, Safely**
  - **Real-Time On-Scene Tactical Support (Enables Tactical Decision Aids)**
    - **Critical to Precision Guided Munitions, Mission Planning, P(K) Effectiveness**
    - **Protection and Avoidance of Nuclear Biological and Chemical (NBC) Agents**
    - **Optimum Ship Routing and Tropical Cyclone Avoidance**
    - **Surf Index-Amphibious Assault and Special Operations**
    - **Search and Rescue Operations**
  - **Program's Relationship to Joint Arena**
    - **Navy Commitment to Joint DoD (DMSP) and Merged DoD/DOC National (NPOESS) Satellite Programs**
    - **Navy Lead in Developing/Maintaining NPOESS Ocean Remote Sensing Technology**

WindSat Mission Objectives

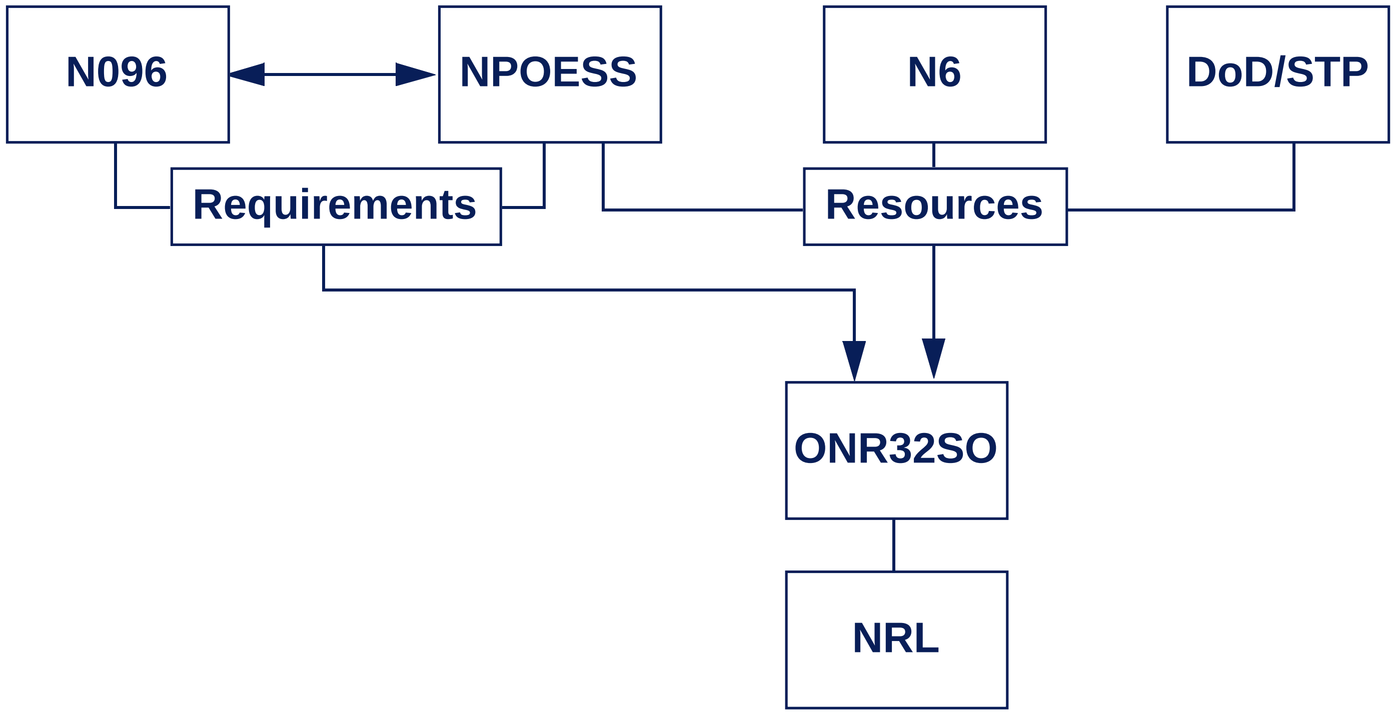
- Demonstrate the Technology to Measure Stokes Parameters From Space on a Worldwide Basis Through Application of Polarimetry to Measure the Ocean Surface Wind Vector (Speed and Direction)

- Demonstrate Support to the Warfighter With Real Time Tactical Downlink of Radiometer Products Directly From Spacecraft to the Field

- Through Space Test Program, Integrate the Class B/C Developed Sensor and Secondary STP Experiments on a Modified Commercial Spacecraft Bus and Launch Satellite As Part of the First Evolved Expandable Launch Vehicle (EELV) Program

- Transfer Technology (Science, Hardware, Algorithm and Software) to National Converged Weather Satellite Program (NPOESS) for Risk Reduction in Future Systems

WindSat Sponsor, Requirements, and Resource Flow



WindSat Performance Goals

Parameter	*Accuracy*			*Range*			*Spatial Resolution*		
System	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD
Wind Speed	± 2 m/s or 20%			3-25 m/s			25 km*	20 km	
Wind Direction	±20° (8-25m/s) ±45° (3-8 m/s)		±20° (3-25m/s)	0-360°			25 km	20 km	

* Driven by Antenna Size

WindSat Secondary Products

Parameter	*Accuracy*			*Range*			*Spatial Resolution*		
System	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD	WindSat	CMIS	NPOESS/IORD
Sea Surface Temperature	0.5K		0.5C	271-313 K		-2 to 40 C	60 km	50 km	1 km
Soil Moisture (Skin Layer: 0.1 cm Depth)	10 cm/m (Bare Soil with Known Soil Type		±10 cm/m Bare Soil With Known Soil Type (Low Horizontal Resolution-Cloudy) ±20 cm/m (High Resolution-Clear)	0-100 cm/m			60 km	40 km	1 km Clear, Nadir 4 km Clear Worst Case 40 km Cloudy Nadir 50 km Cloudy, Worst Case
Snow Cover	Depth > 0 cm Coverage 20%		± 10% snow/ no snow	Any Depth 0-100%		0 - 40 cm	25 km	12.5 km	1.3 km Clear 12.5 km Cloudy
Sea Ice (Orbit Dependent)	70% Probability of Correct Typing		70% Probability of Correct Typing 1 Yr vs. 2+ Yr ice	First Year, Multi-Year		1 to 36+ month	25 km	20 km	3 km
Water Vapor	2 mm or 10%			0-75 mm			25 km		
Cloud Liquid Water	0.25 mm		±0.50 mm over ocean ±0.25 mm over land	0-50 mm			25 km	20 km	

WindSat Mission Success Criteria (1 of 2)

Within the Program Constraints of a Single Satellite Constellation Consisting of a Government Developed Sensor Integrated Onto a Modified Satellite Bus; Compatible With Taurus Class Launch Vehicle, Scheduled for Launch on an EELV in June, 2001 Into a 55° Inclined Orbit; the Engineering Implementation Shall Provide:

1. **Demonstration of Space-Based Multi-Channel Passive Microwave Polarimetric Radiometry As a Reliable and Cost Effective Means for Measuring Global Ocean Wind Vector (Wind Speed and Direction) Data That Meets Navy and NPOESS Requirements**

2. **Capability to Measure the Following Additional Environmental Data Types, Sea Surface Temperature and Those Generally Associated With Passive Microwave Imagery, Integrated Atmospheric Water Vapor, Cloud Liquid Water, Rain Rate, Sea Ice, Snow Cover, and Soil Moisture**

3. **Direct Downlink Capability to Demonstrate the Capability to Provide On-Scene Users With Near-Real Time Access to the WindSat Data for Retrieval of Wind Vector and the Other Environmental Data Types Outlined in (1) and (2)**

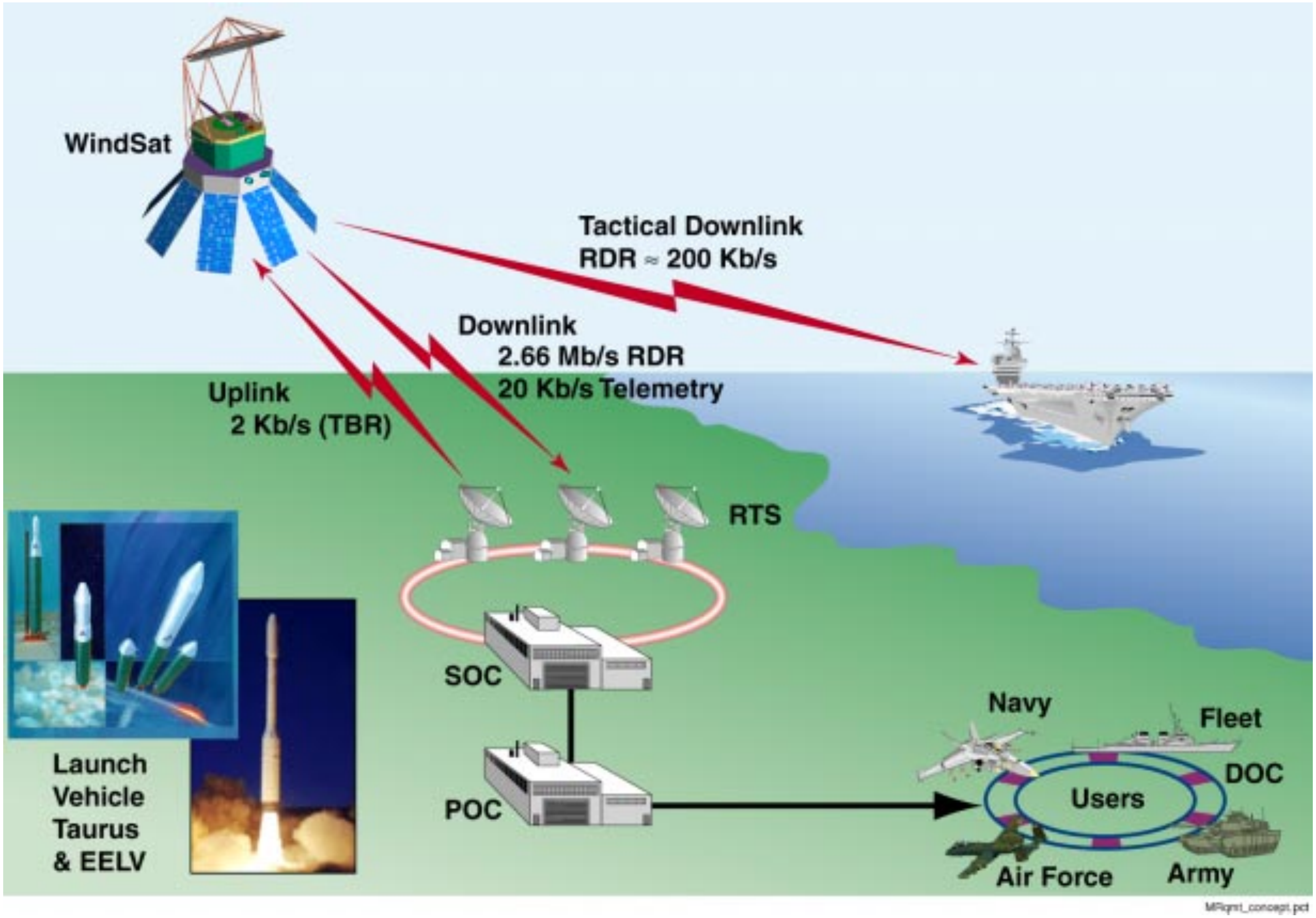
WindSat Mission Success Criteria (2 of 2)

4. **Integration Into the NPOESS Phase I Ground Control Architecture and Conformance With Command, Control, and Communications (C3) Requirements**

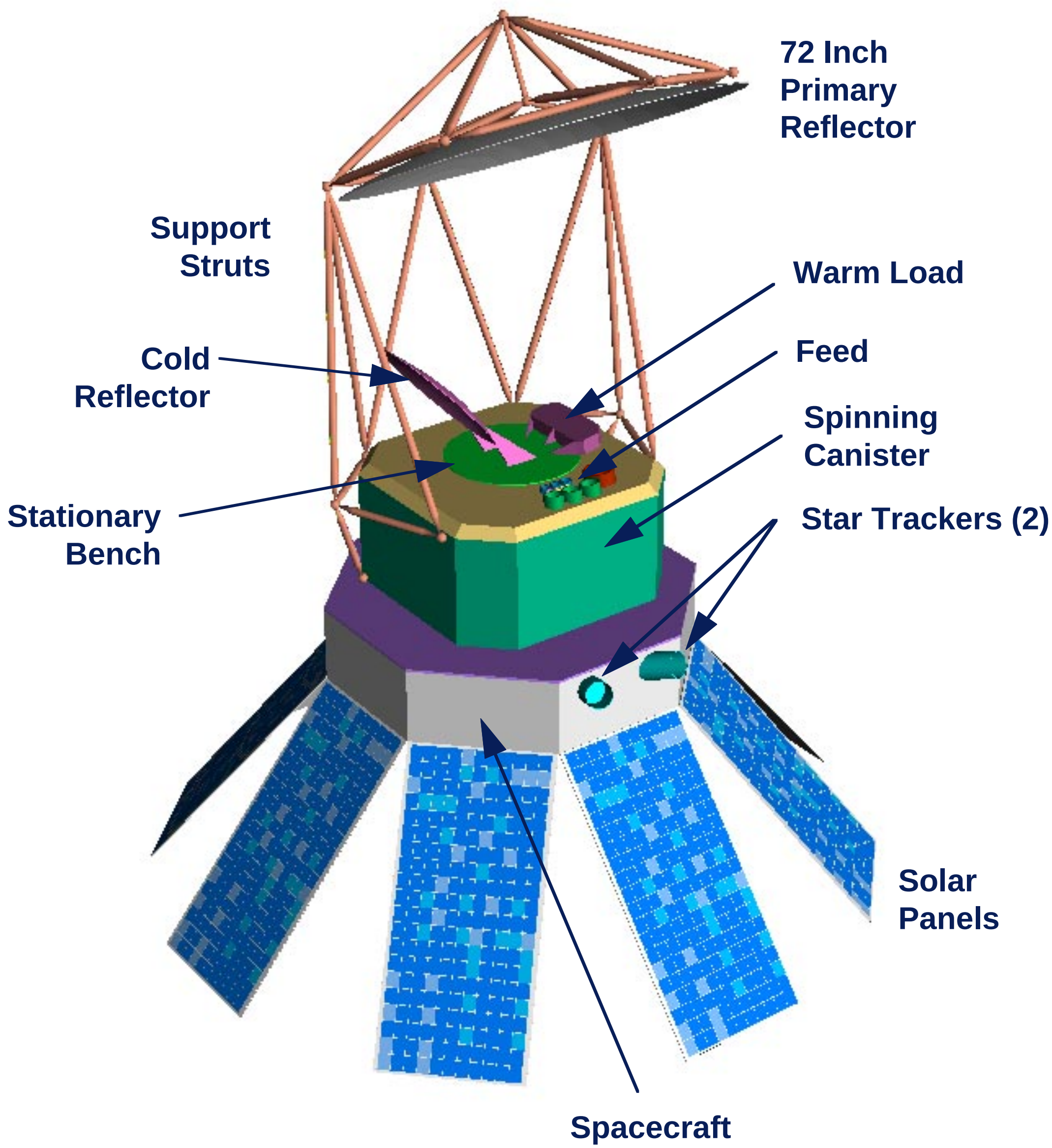
5. **Transition of Passive Microwave Polarimetric Radiometry Technology for Use in the Development and Production of the NPOESS Conical Microwave Imagery and Sounder (CMIS)**

Element	*WindSat Requirement/Objective*
Mission	
Duration	1 Year / 3 Year
Duty Cycle	Ocean/100%
Launch Vehicle	
Orbit	55° Inclination 850km Altitude
Secondary STP Experiments	
Duration	One Year
Data Collect	> 6 Months

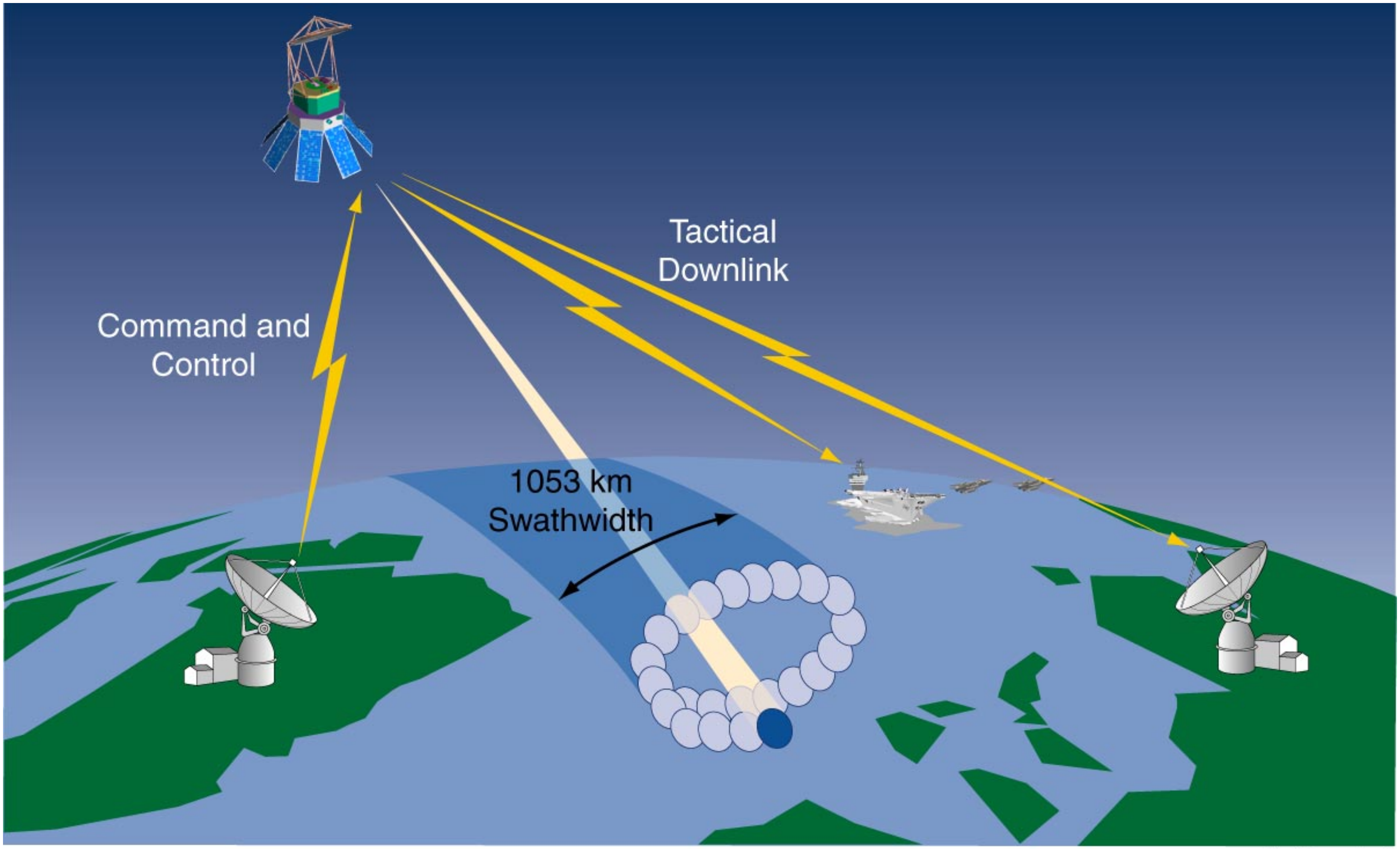
WindSat Top Level Architecture



WindSat Concept Structure Definition



WindSat Swath Width



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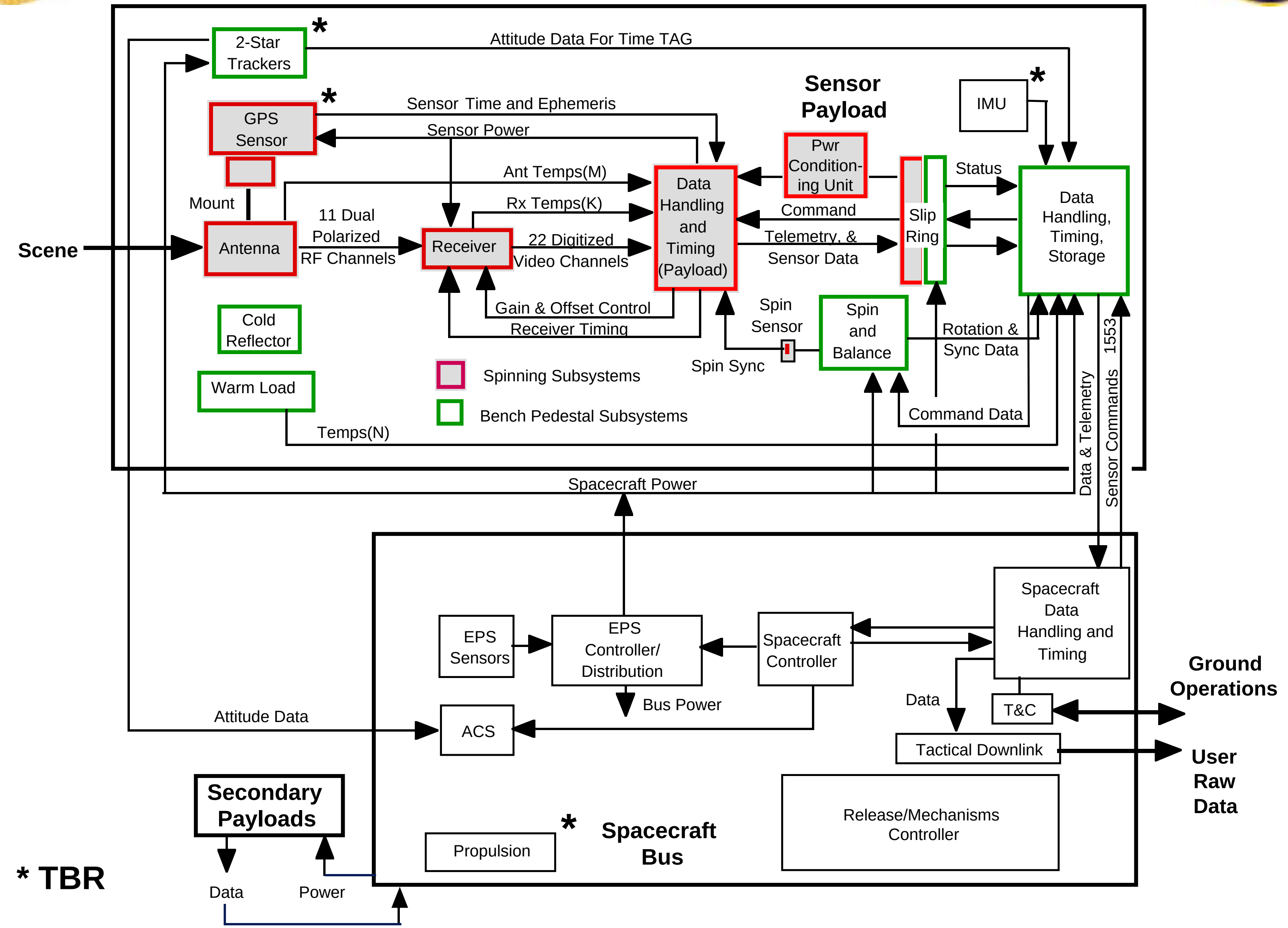
Subsystem Interfaces



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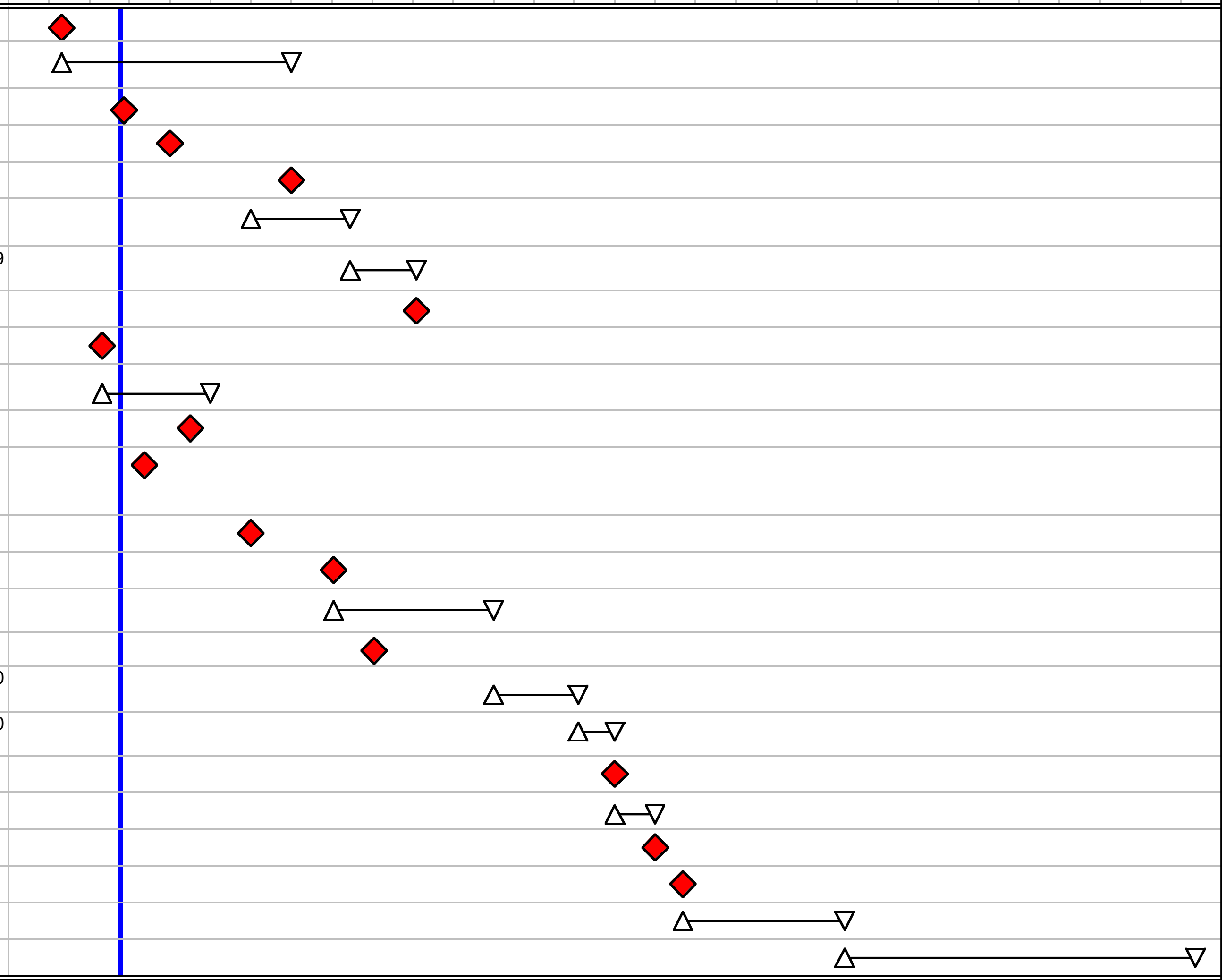
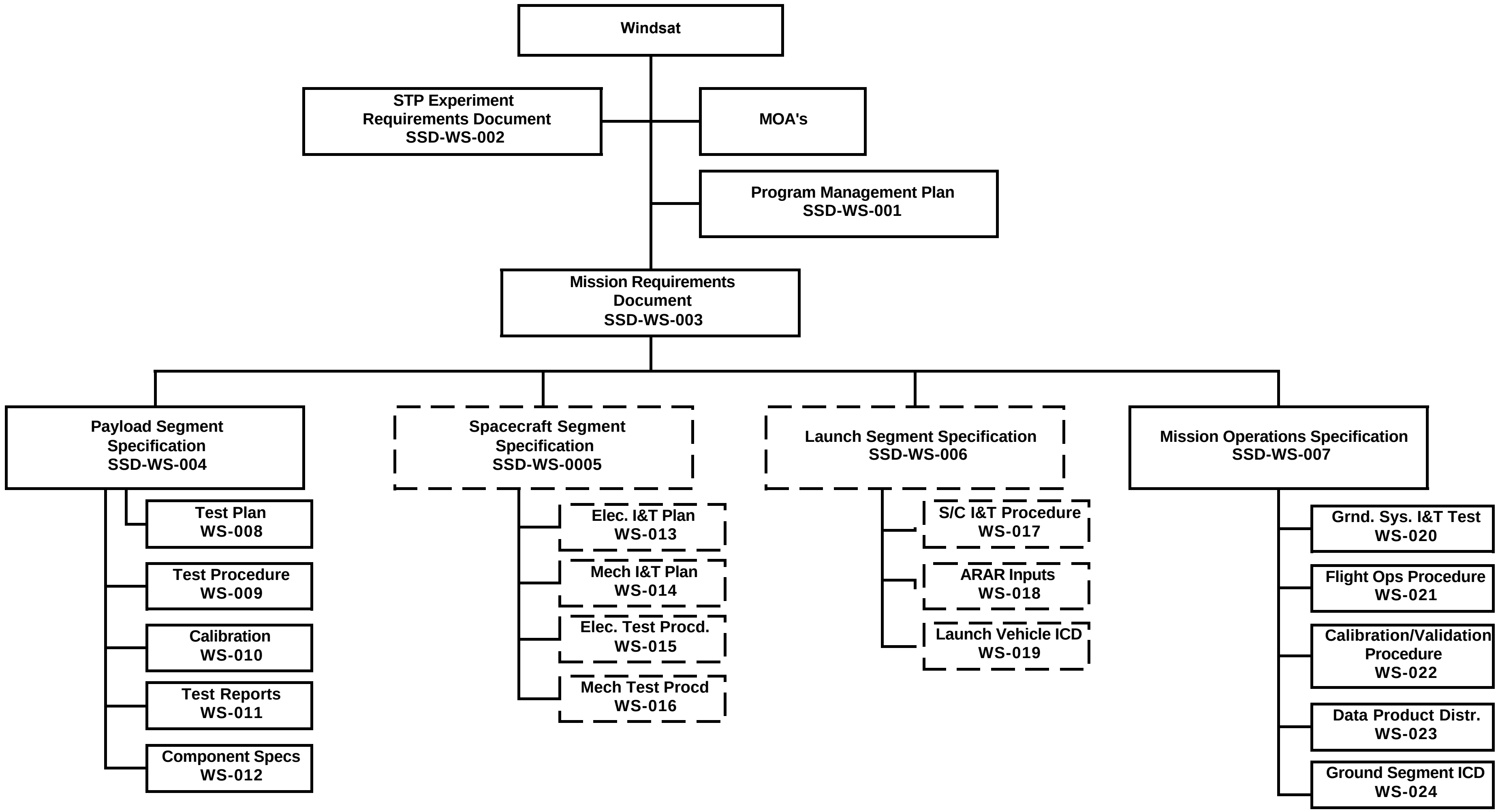
WindSat Schedule

Activity Name	Start Date	Finish Date
Program ATP	8/1/97	
P/L Design & Qual Development	8/1/97	1/2/99
P/L SRR	12/17/97	
P/L PDR	4/1/98	
P/L CDR	1/2/99	
Flight P/L Fabrication	10/1/98	5/11/99
P/L Integration & Tes	5/11/99	10/11/99
P/L Delivery to S/C	10/11/99	
End Bus Study	11/1/97	
Bus RFP & S/C Desig Development	11/1/97	6/29/98
S/C SRR	5/17/98	
Bus Contract Award & Secondary Decision & LV Decision	2/1/98	
S/C PDR	10/1/98	
S/C CDR	4/4/99	
S/C Mods & Integratic	4/4/99	4/1/00
COTS Bus Delivery	7/4/99	
STP Experiment Integration	4/1/00	10/11/00
Windsat P/L Integrati	10/11/00	12/31/00
System TRR	12/31/00	
System Env. Testing	12/31/00	4/1/01
S/C Ship	4/1/01	
Launch	6/1/01	
Cal/Val	6/1/01	6/1/02
Ops Demo	6/1/02	8/1/04



	FY 1997		FY 1998				FY 1999				FY 2000				FY 2001				FY 2002				FY 2003				FY 2004			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4	FQ1	FQ2	FQ3	FQ4
Untitled	0	2	3	1	2	0	2	1	3	1	1	0	1	0	3	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3

WindSat Document Tree



Configuration Management

- **The WindSat Program Will Follow the Guidelines of NCST's Configuration Management Plan (SSD-D-005J)**
  - **All Changes to Hardware and Software Under Configuration Management Will Be Controlled by the Configuration Control Board (CCB) Which Will Consist of the Program Manager, Mechanical Systems Lead, Electrical Systems Lead, and the Pertinent Sub-System Engineer(s)**
  - **Configuration Changes Will Be Documented Using Configuration Change Notices (CCNs)**
  - **No Flight Hardware/Software Will Be Integrated Until It Has Been Released by the CCB**

Product Assurance

- **WindSat Hardware / Software Will Be Inspected, Tested, and Controlled Per the Product Assurance Plan (SSD-D-IM008) As Modified by the WindSat Program to Meet Its Requirements**
  - **Hardware That Does Not Meet Released Drawing / Specification Will Have a Non-Conforming Material Report (NMR) Generated Against It**
    - **NMRs Will Be Dispositioned by the Pertinent Subsystem Engineer, and Signed off by the CCB Including the Program Manager's Quality Control Designee**
  - **All Hardware at the Piece-Part Level Will Be Tracked by Traveler to Verify Its Fabrication and Build History**
  - **All Hardware / Software Will Be Tested Per WindSat Procedure**
    - **Performance Discrepancies Will Be Documented by Discrepancy Reports (DRs) Which Will Be Dispositioned Like NMRs**
  - **The Program Manager's Quality Control Designee Will Keep an As-Built Configuration List (ABCL) of the WindSat Flight Hardware**
    - **This List Is the Culmination of All WindSat CM/PA Documentation, and Will Be Reviewed Prior to System Level Environmental Testing (TRR), and at Buyoff**

Hardware Philosophy

- **The WindSat Experiment Is a Demonstration Payload and As Such Will Be Developed As a DOD-HDBK-343 Class B / C Program**
  - **(B) Medium Life - 3 Years**
  - **(C) Medium Complexity - Not Developing a Technology, But May Use State-of-Art**
  - **(B) Limited Flight Spares - See Sparing Policy**
  - **(B) Limited Use of Redundancy - Use Only Where Necessary**
  - **(C) Low Cost - Meet Funding Profile**

- **Does <u>Not</u> Mean Low Reliability**

Program Risk and Mitigation

- Risk Watch Items Are Technical and/or Program Issues Identified With Risk That Require Increased Program Visibility
  - Determined During Technical and Project Review
  - Requires Risk Mitigation Plan
  - Reviewed and Updated Monthly

WindSat Risk Watch List

No.	Risk	Type	Level	Mitigation	Who
1	Launch Vehicle	Schedule Cost	High	• Monitor Schedule/Development • Decision by 2/1/98	Koss
2	Spacecraft	Tech/Cost	High/High	• Simplify Interfaces • Decision by 2/1/98	Spencer
3	Antenna Pattern Characterization	Tech	High	• Test Range Capabilities/Enhancements • Evaluate Alternate Facilities	Bartlett/ Lippincott
4	Receiver Detector Linearity/System Noise	Tech	High	• Screening Selection Program • Testing	Gaiser/Xavier
5	Calibration	Tech	Medium	• Target Characterization • Availability of APMIR	Gaiser/Poe
6	EMI/EMC	Schedule Tech	Medium	• Design/Fab/Test Procedures • EMI Control Plan	Webster
7	Spin/Slip Ring Assembly	Tech	Medium	• Redundancy/Contact Design • Prototype Testing	Koss/Plourde
8	Polarization Purity	Tech	High	• Test and Alignment	Gaiser/Purdy

Major Conceptual
Design Trades in Process

- Feed Architectural Alternatives
  - Stokes Vector Horns
  - Stokes Beam Forming
  - Optimization of Layout for Polarimetry
- Cold/Warm Load Concepts/Layouts/Packaging/Max Swath
- Spin Rate/Feed/Altitude/Sensor Size/Nyquist/Data Rate
- Polarization Purity Characterization and Validation
- NEDT Technology Requirements/Availability/Heritage
- Refinement of Bias and Random Partitioning
- Weight/Power/Off-the-Shelf/Custom/Minimization Studies

Spacecraft Bus Status and Secondary Experiments

Spencer

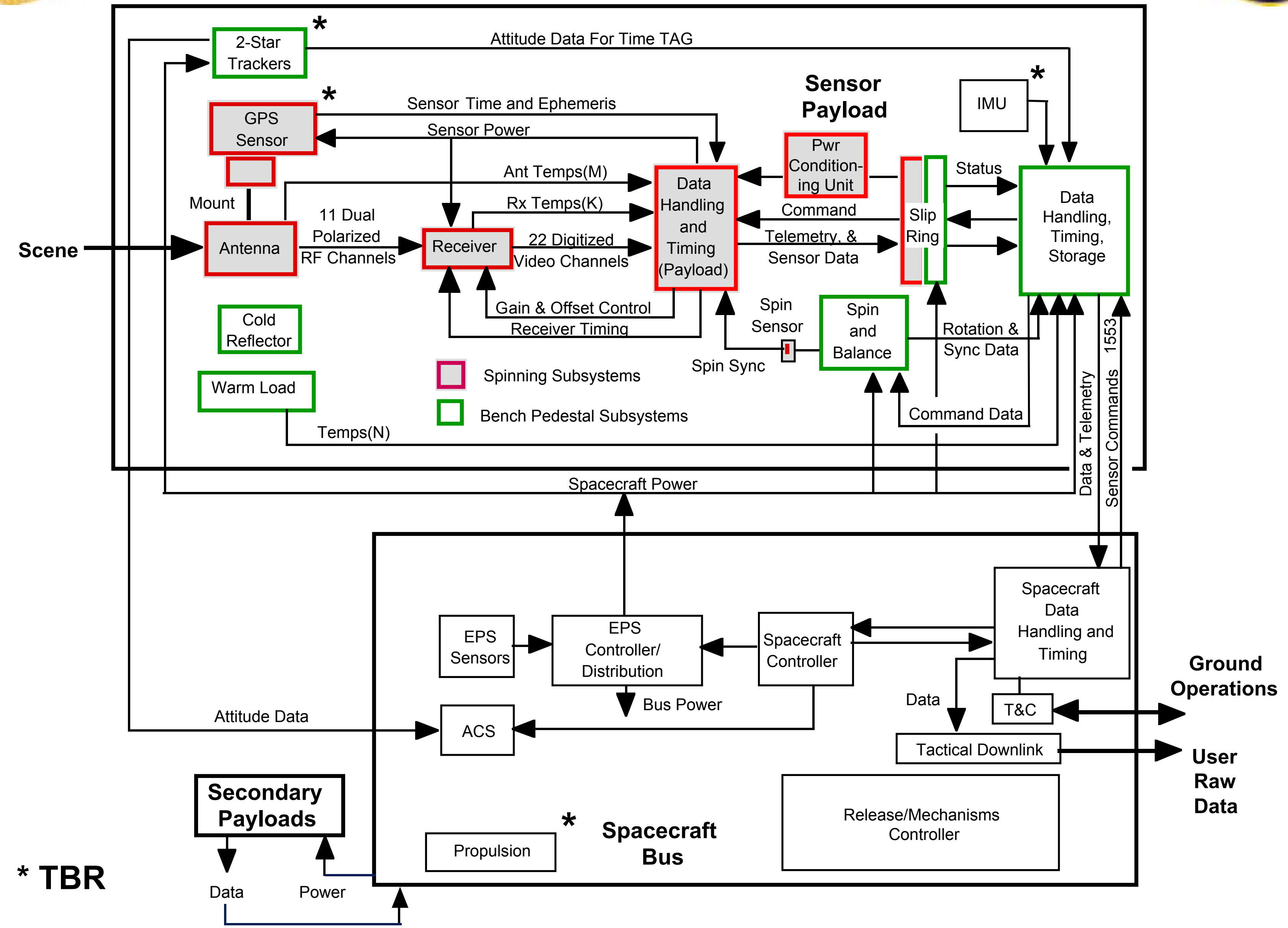
Spacecraft Bus Status

- A Commercial / Production Bus Survey Was Conducted for the DoD Space Test Program
  - No Production Buses Are Fully Capable to Support the WindSat Program
  - There Is Not a “Perfect Fit” Commercial Spacecraft That Can Support the WindSat Program Constraints of Cost and Performance
  - All Commercial Spacecraft Will Need to Be Modified to Fly the WindSat Payload
- At Present the WindSat Program Is Awaiting Direction on a Spacecraft Acquisition Plan
- For the Purposes of This SRR, an Ideal Custom Bus Is Being Derived to Aid in Establishing Subsystem Performance Specs, Environments, and Interface Definitions for the Payload

Payload / Spacecraft Interfaces

- The WindSat Payload Is Being Designed to Have As Simple an Interface As Possible
  - Necessary to Support Undefined Bus
  - Although This Makes the Payload More Expensive by Making It More Capable, It Will Allow for Near Term Detailed Payload Development As Well As Easier Spacecraft Bus Acquisition

Subsystem Interfaces



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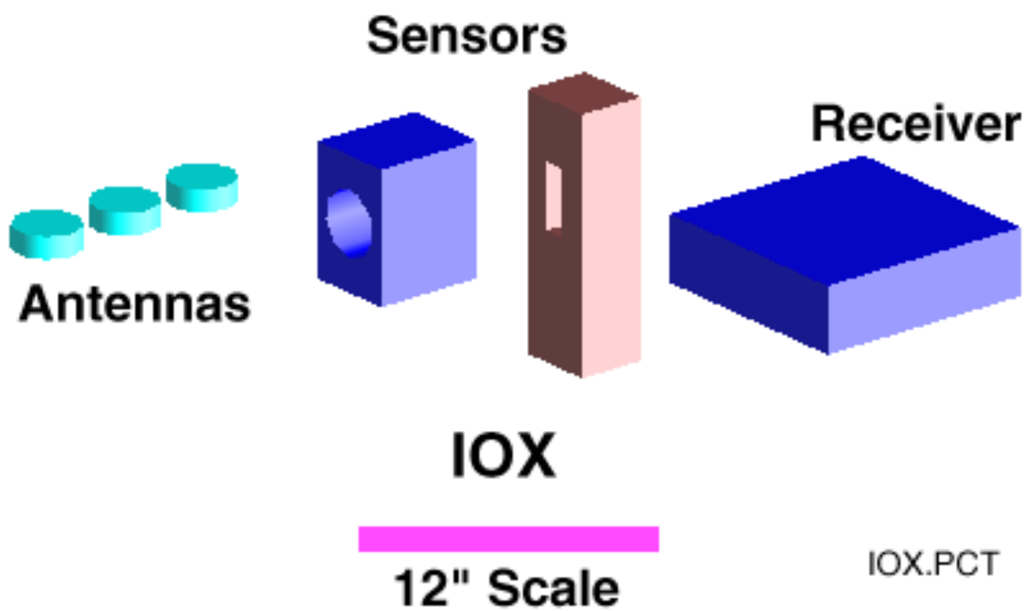
STP Payloads Study (1 of 5)

- **STP Requirements**
  - **Concentrate on Integrating SMEI and IOX**
  - **Keep Flexibility on Manifesting Other STP Experiments as Late as Possible - Unofficial 1998 SERB List Will Be Available in February 1998**

STP Payloads Study (2 of 5)

- IOX
  - Sense Ionospheric Density Profiles During Earth-Limb Occultation of GPS Satellites to Obtain Data for FUV/EUV Technique Validation and Obtain Topside and Plasmaspheric Data
  - Developed By:
    - Air Force Research Lab (AFRL)
    - Aerospace Corporation
  - FOV:
    - FUV/EUV Sensors - Nadir Pointing 5 - 10 Degree Cone Angles
    - Antennas - +/- X and +Z Directions
    - Power: 11 W OAP
    - Weight: 8 Kg

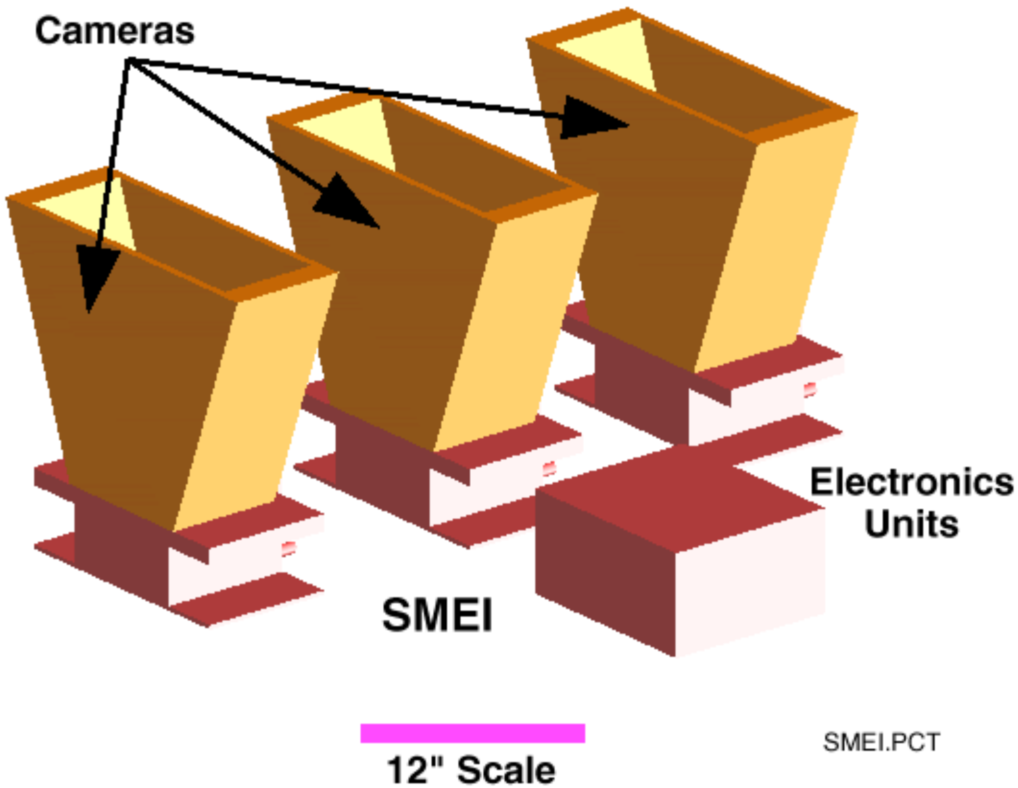
STP Payloads Study (3 of 5)



STP Payloads Study (4 of 5)

- SMEI
  - Proof of Concept Experiment for Tracking the Progress of Interplanetary Disturbances in Visible Light from the Sun to the Earth
  - Developed By:
    - AFRL
    - University of California at San Diego (UCSD)
    - University of Birmingham
  - FOV: 180 Degrees of Deep Space - Three (3) Cameras, Each With a 60 x 3 Degrees FOV
  - Power: 32 W OAP
  - Weight: 30 Kg
  - Camera Issues
    - Baffles Need Dark Environment
    - Experimenter Presently Working on How Much Light the Camera's Can Withstand

STP Payloads Study (5 of 5)



Science Mission Requirements

P. Gaiser

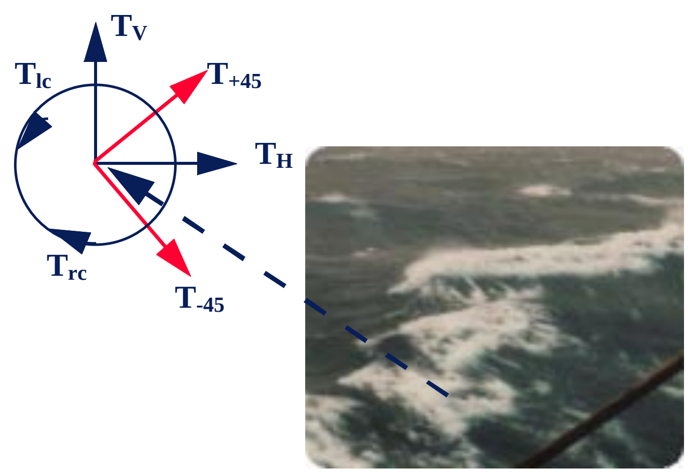
WindSat Science Mission

- Definition of Polarimetric Radiometry
- Aircraft Data
- WindSat Radiance Simulation Model
- Overview of WindSat Sensitivity Analysis
- Summary of WindSat System Requirements

Polarimetric Radiometry

- **Ocean Surface Emission Varies With Wind Speed and Direction**
- **SSM/I Wind Speed Retrievals Are Being Used Operationally With Accuracy Better Than ±2 m/s**
- **Aircraft Measurements Have Shown That the Wind Direction Signal Is Measurable From 10–37 GHz at Broad Range of Wind Speeds**
- **Wind Direction Dependence Arises From Anisotropic Distribution and Orientation of Wind Driven Waves**
- **Polarimetric Radiometry Measures the Stokes Vector Which Describes the Polarization Properties of the Emitted Radiation**
- **Stokes Vector Contains Information Needed to Measure the Ocean Wind Vector**

$$I_s = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} T_v \\ T_h \\ T_{45} - T_{-45} \\ T_{lc} - T_{rc} \end{bmatrix} = \begin{bmatrix} \langle E_v E_v^* \rangle \\ \langle E_h E_h^* \rangle \\ 2\,\mathrm{Re}\langle E_v E_h^* \rangle \\ 2\,\mathrm{Im}\langle E_v E_h^* \rangle \end{bmatrix}$$



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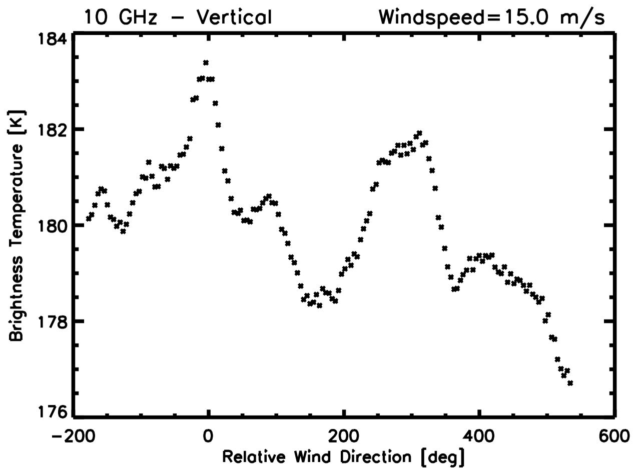
Airborne Experiments

- Polarimetric Microwave Radiometer Data at 10.7, 19.35 and 37 GHz
  - Majority of Measurements Are of Tv, Th, U; V Capability Added in 1995
- Circle Flights Around National Data Buoy Center Buoys or Circles Around Falling Dropsonde
- 45, 55, and 65 Degree Incidence Angles
- 2 - 35 m/s Wind Speeds; Clear Sky and Cloudy Conditions
- Data Set Limitations
  - Small Data Set Relative to Global Conditions; All Data Collected off U.S. Coast
  - Limited Wave Spectra Data
  - No Atmospheric Ground Truth; Atmospheric Information Obtained From Other Radiometers and / or Dropsondes
- These Ongoing Efforts Have Demonstrated:
  - Clear Azimuthal Variation in Incidence Angle Range of 45° to 65°
  - I and Q Have Even Symmetry; U and V Have Odd Symmetry
  - Measurable Wind Direction Signal As Low As 2 m/s and As High As 35 m/s
  - Retrievals Using Aircraft Data Show Best Performance at 55° and 65°

Aircraft Data, 10 GHz, w = 15 m/s



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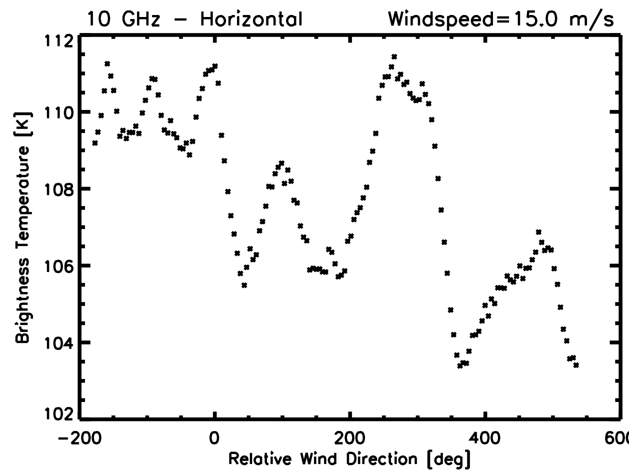

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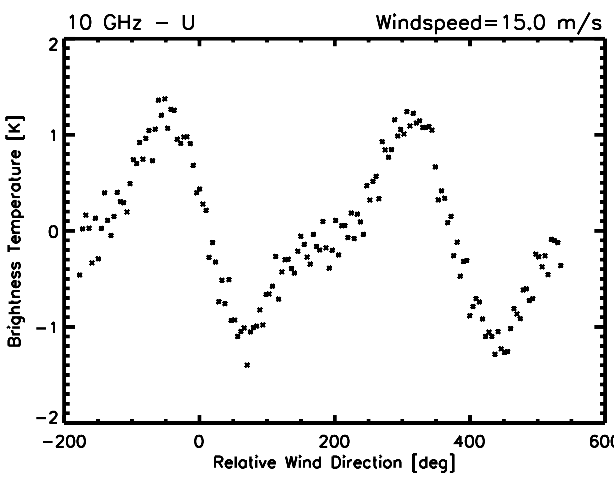

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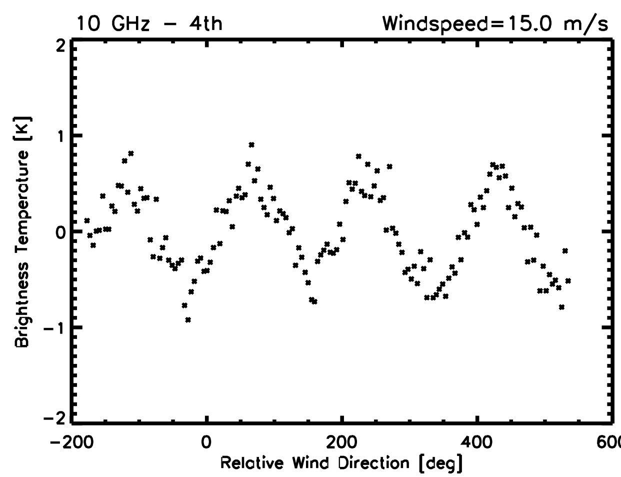

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Aircraft Experiment Validation

- The NOAA National Data Buoy Center Network of Buoys
  - Wind Speed ± 1 m/s
  - Wind Direction ± 10°
  - Data Is 8 Minute Average Reported Every Ten Minutes
  - Buoys Also Provide Sea Surface Temperature, Air Temperature, Surface Pressure, Wave Height, Wave Period
- GPS Dropsondes (Secondary Source of Truth Used Where Buoys Are Not Available)
  - Provides Wind Vector With ±0.5 m/s Accuracy
  - Also Provides Humidity, Temperature, Pressure Profile for Descent Path

WindSat Model

Vertical and Horizontal

$$T(p,f,\theta,\varphi) = L\{(1-F)[eT_w + (1-e)T_{sky}]_{sea} + F[eT_w + (1-e)T_{sky}]_{foam}\} + T_{atm}$$

$$e(p,f,\theta,\varphi) = e_{spec} + [\Delta e_0 + \Delta e_1 \cos\varphi + \Delta e_2 \cos 2\varphi]_{rough}$$

U and V

$$T(p,f,\theta,\varphi) = L\{(1-F)[(e_{p(r)} - e_{m(l)})T_w - (e_{p(r)} - e_{m(l)})T_{sky}]_{sea}\}$$

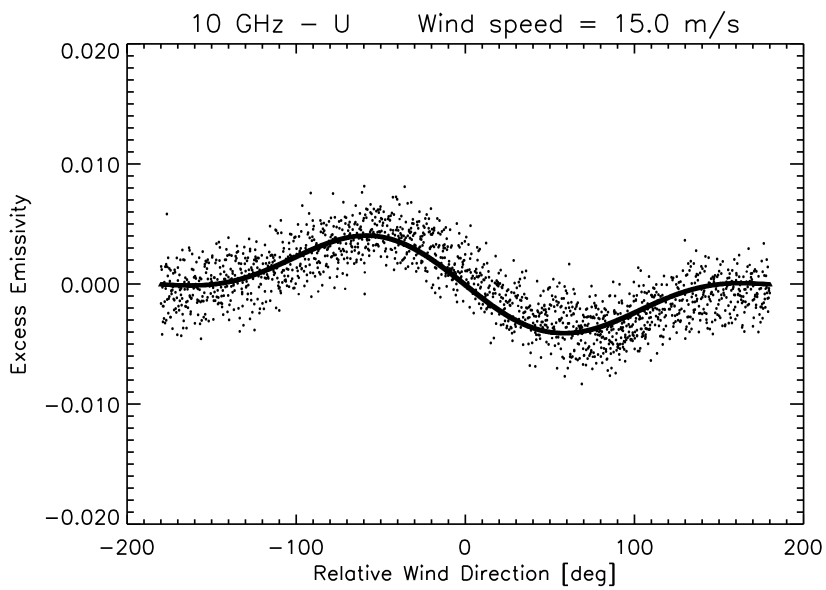
$$(e_{p(r)} - e_{m(l)}) = \Delta e_1 \sin\varphi + \Delta e_2 \sin 2\varphi$$

L = atmospheric loss

F = percent of foam coverage

- **Emissivity Uses Specular Plus Wind Roughened Surface**
  - **Hollinger Wave Effect Emissivity Model Used for Isotropic Roughness**
  - **Directionally Dependent Emissivity Terms Derived From NRL/JPL Aircraft Data Set (U and V)**
  - **T_v and T_h Direction Terms Derived From SSM/I Buoy Matchup Data Base**
  - **Foam Coverage From Stogryn**

Stokes Emissivity Model Derived From Aircraft Data



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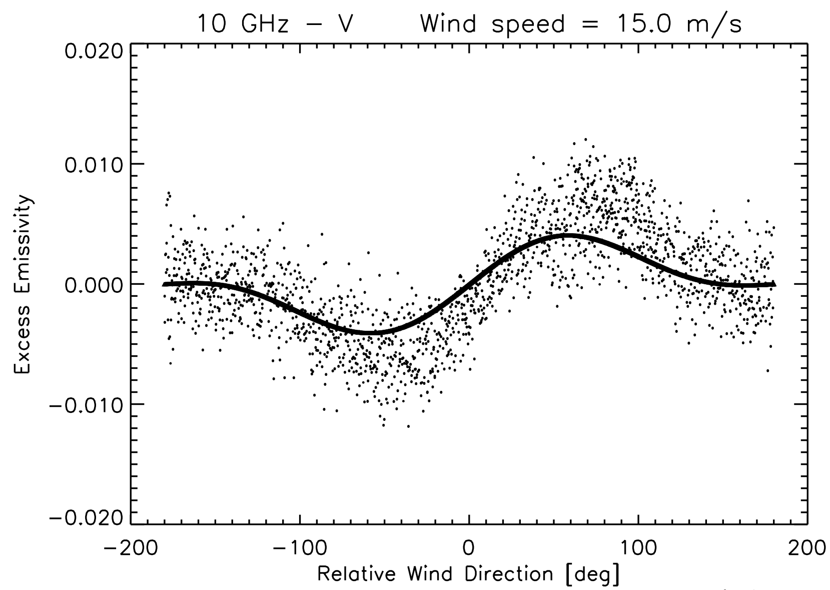

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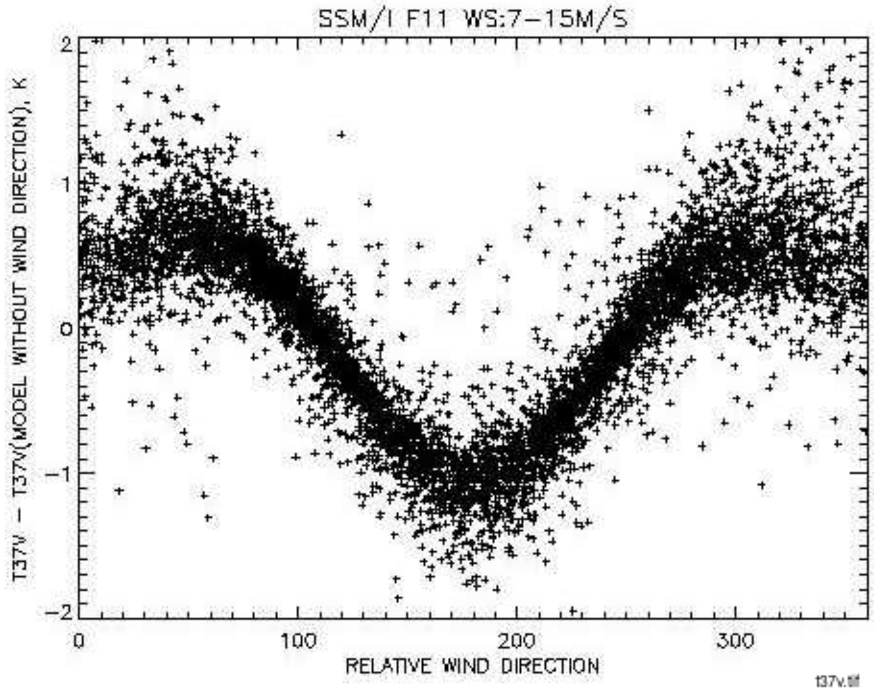
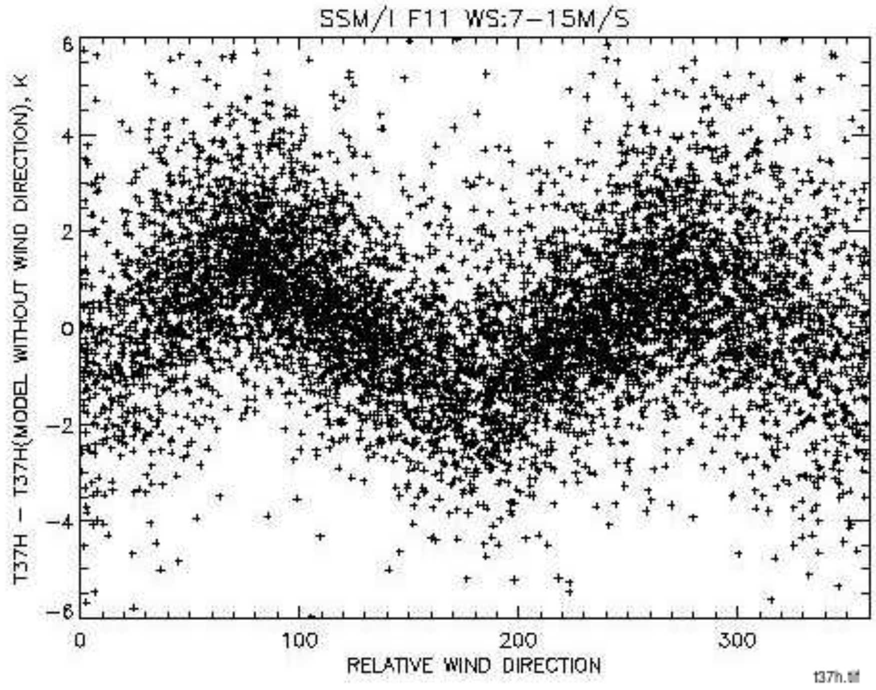
SSM/I Wind Vector Modeling

- **NRL Has Compiled Extensive Buoy–SSM/I Matchup Data Base**
- **SSM/I Data Used to Model Vertical and Horizontal Polarization Wind Direction Signature**
- **Validates Extending Models to Space**

Vertical



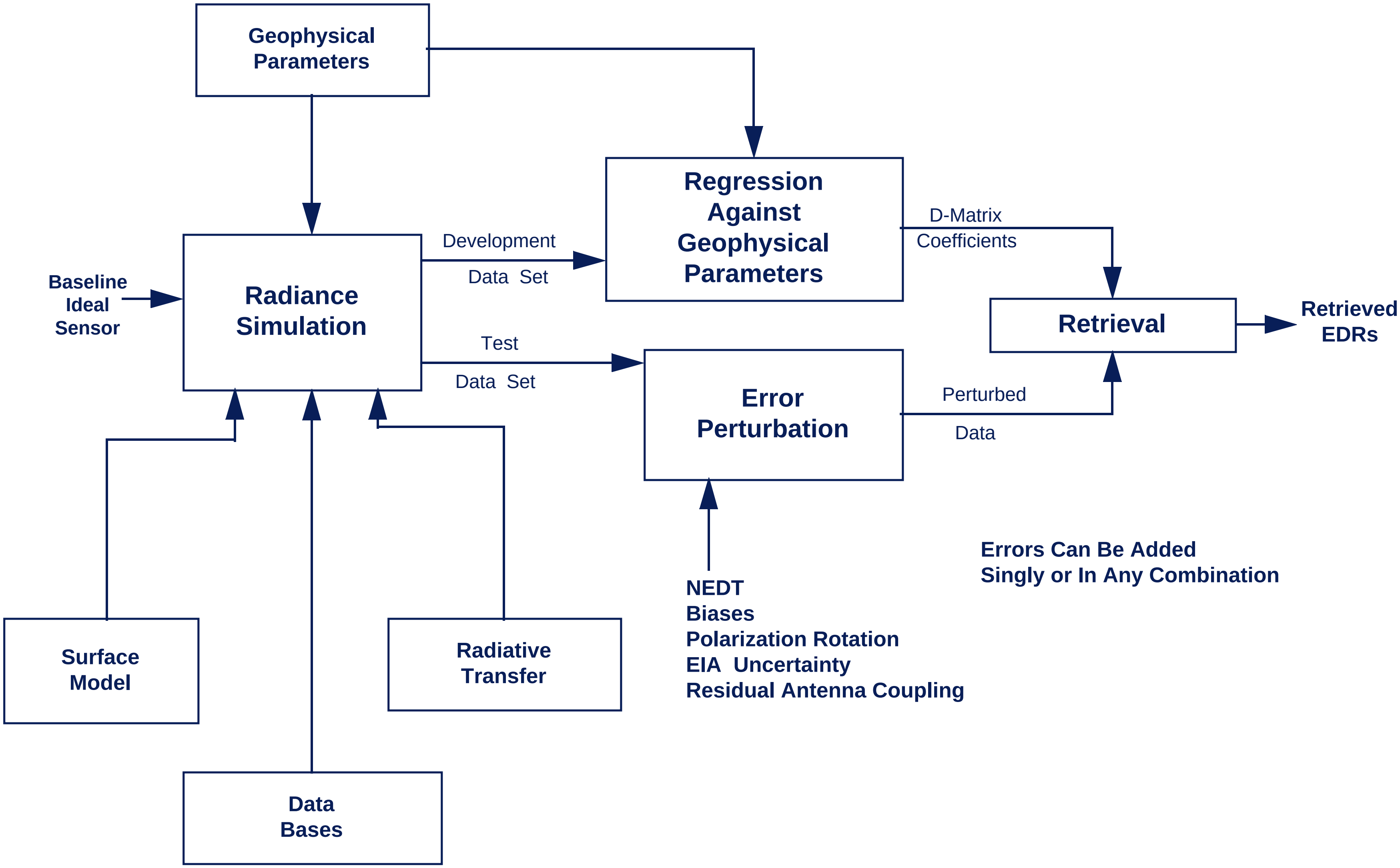
Horizontal



WindSat Mission Science Goals

- **Mission Science Goals Are Determined by the Capability of the WindSat System to Retrieve the Ocean Surface Wind Vector**
  - **Wind Speed** ±2 m/s or 20%
  - **Wind Direction** ±20° (8-25 m/s) ; ±45° (3-8 m/s)
- **The WindSat Goals Result in a Sensor Capable of Retrieving Other Environmental Data Records (EDR)**
- **Secondary EDRs Do Not Drive the WindSat System Requirements**

Sensitivity Analysis



Errors Can Be Added
Singly or In Any Combination

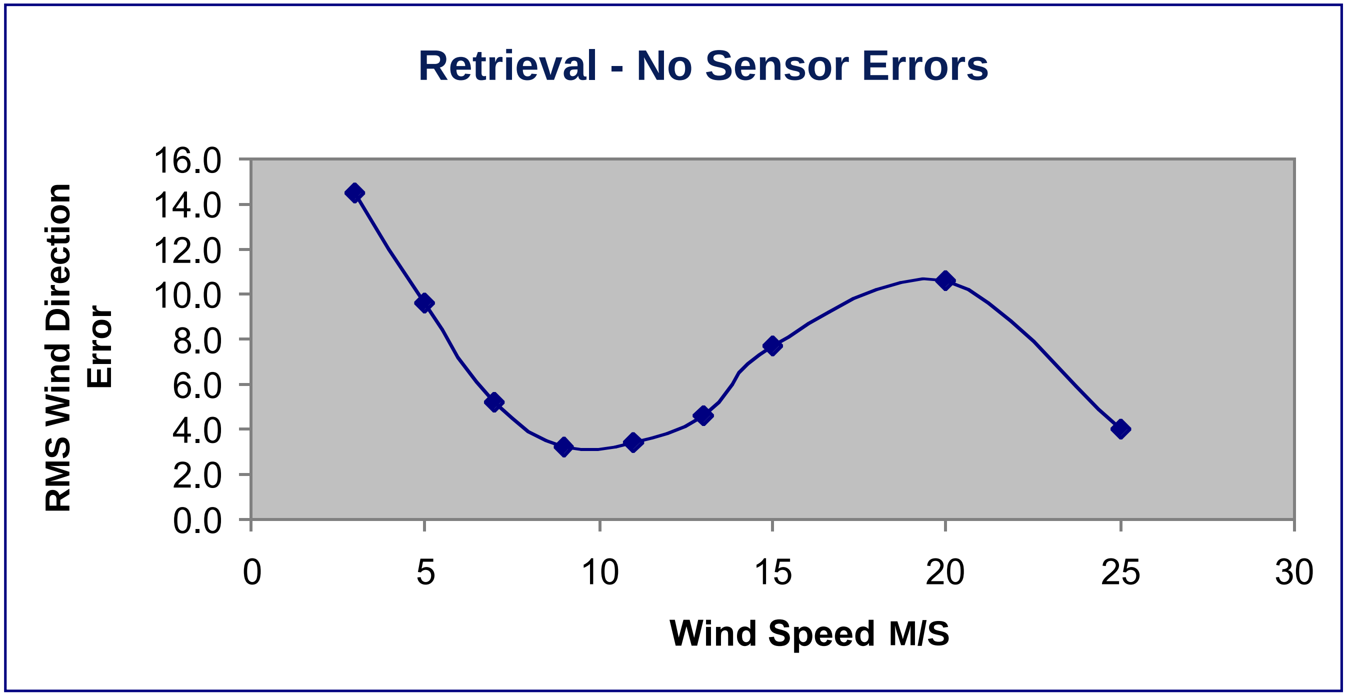
Wind Direction Sensitivity Analysis Results

- **Output Is RMS Wind Direction Error**
  - **Based on 5000 - 6000 Cases**
  - **Each Case Has Randomly Generated Error Terms According to Requirements Allocated to Subsystems**
- **Use to Optimize and Validate Error Budget Allocations**
- **Will Be Used to Optimize Retrieval Algorithms**
- **Will Be Ongoing Through PDR**

Model Performance

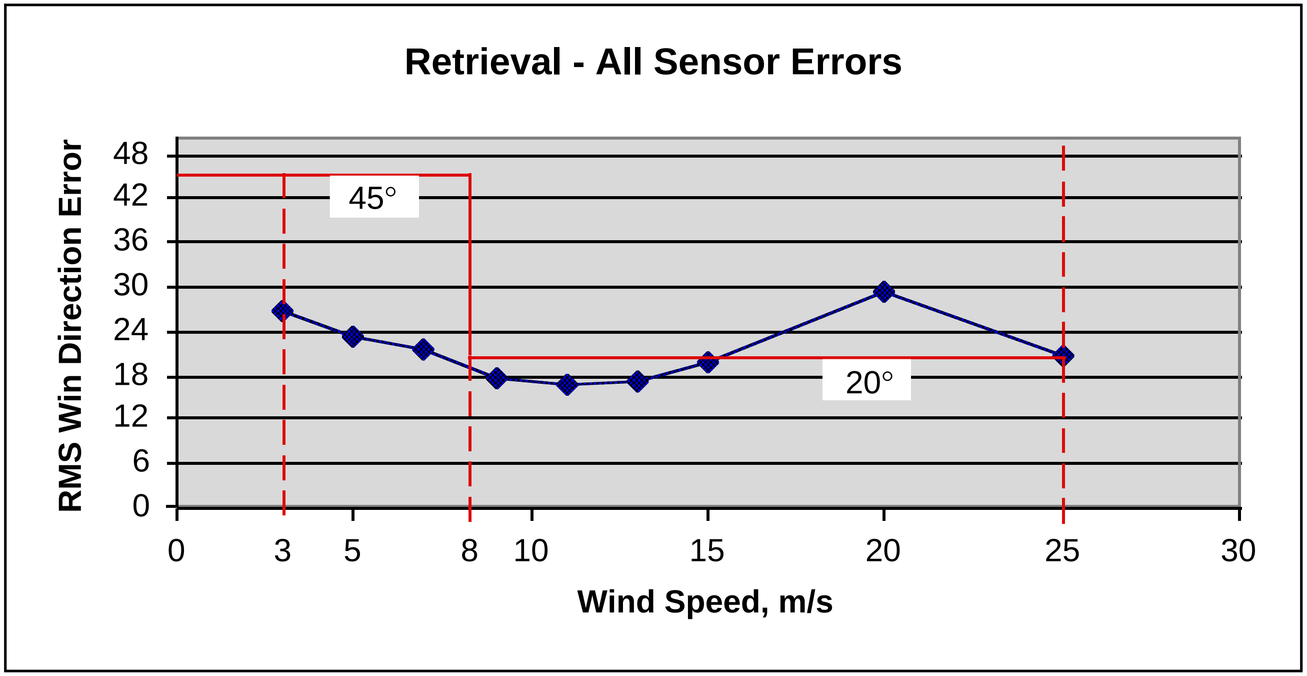
- Baseline Ideal Sensor
  - Fully Polarimetric at 10.7, 18.7 and 37 GHz
  - Dual Linear Polarization at 6.8 and 23.8 GHz
- Geophysical Parameters Included in Model
  - Wind Speed, Wind Direction, Sea Surface Temperature, Salinity, Water Vapor Mass, Cloud Water Mass
- Model Incorporates Uncertainties in Geophysical Parameters
- Arctic, Temperate and Tropical Atmospheres
  - Four Seasons
  - Clear and Cloudy
  - Non Precipitating
- With Full Complement of Sensor Errors and Nominal Global Conditions, Model Retrieves Wind Speed to Within $\pm$ 1.4 m/s RMS

Wind Direction Retrieval Performance



- Inaccuracy Due to Environmental Noise

Wind Direction Retrieval Performance

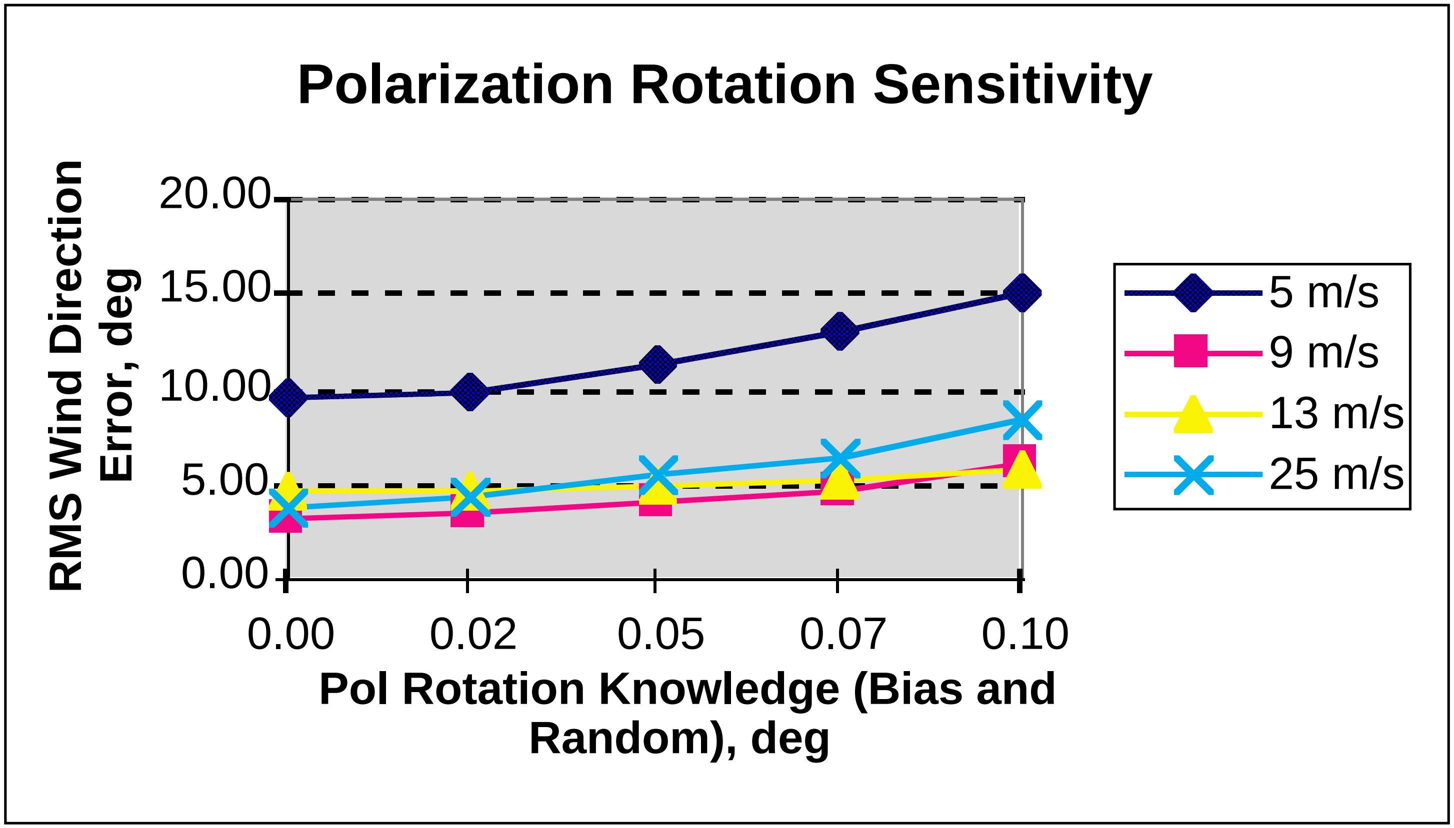


- Inaccuracy Due to Environmental Noise and Sensor Errors

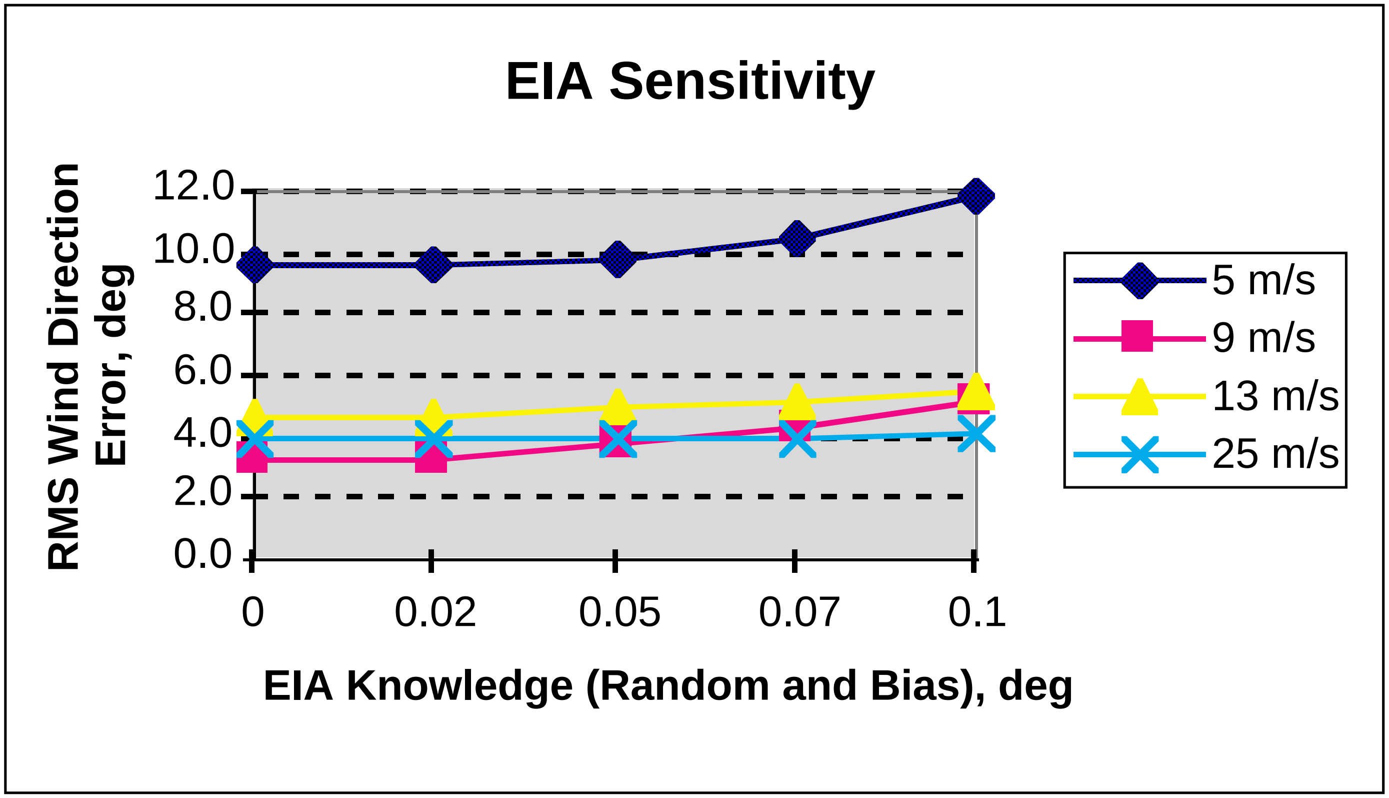
Summary of Derived Requirements

- NEDT - Receiver Noise (Each Single Polarization)
  - 6.8 — 0.20 K
  - 10.7 — 0.15 K
  - 18.7 — 0.15 K
  - 23.8 — 0.20 K
  - 37.0 — 0.10 K
- Calibration Biases (Absolute Accuracy)
  - Linear Polarizations — 0.75 K
  - Polarimetric Channels — 0.25 K
- Residual Antenna Coupling — 0.1% (30 dB)
- Polarization Rotation Knowledge — 0.05°/0.05° (Random/Bias)
- EIA Knowledge — 0.05°/0.05° (Random/Bias)

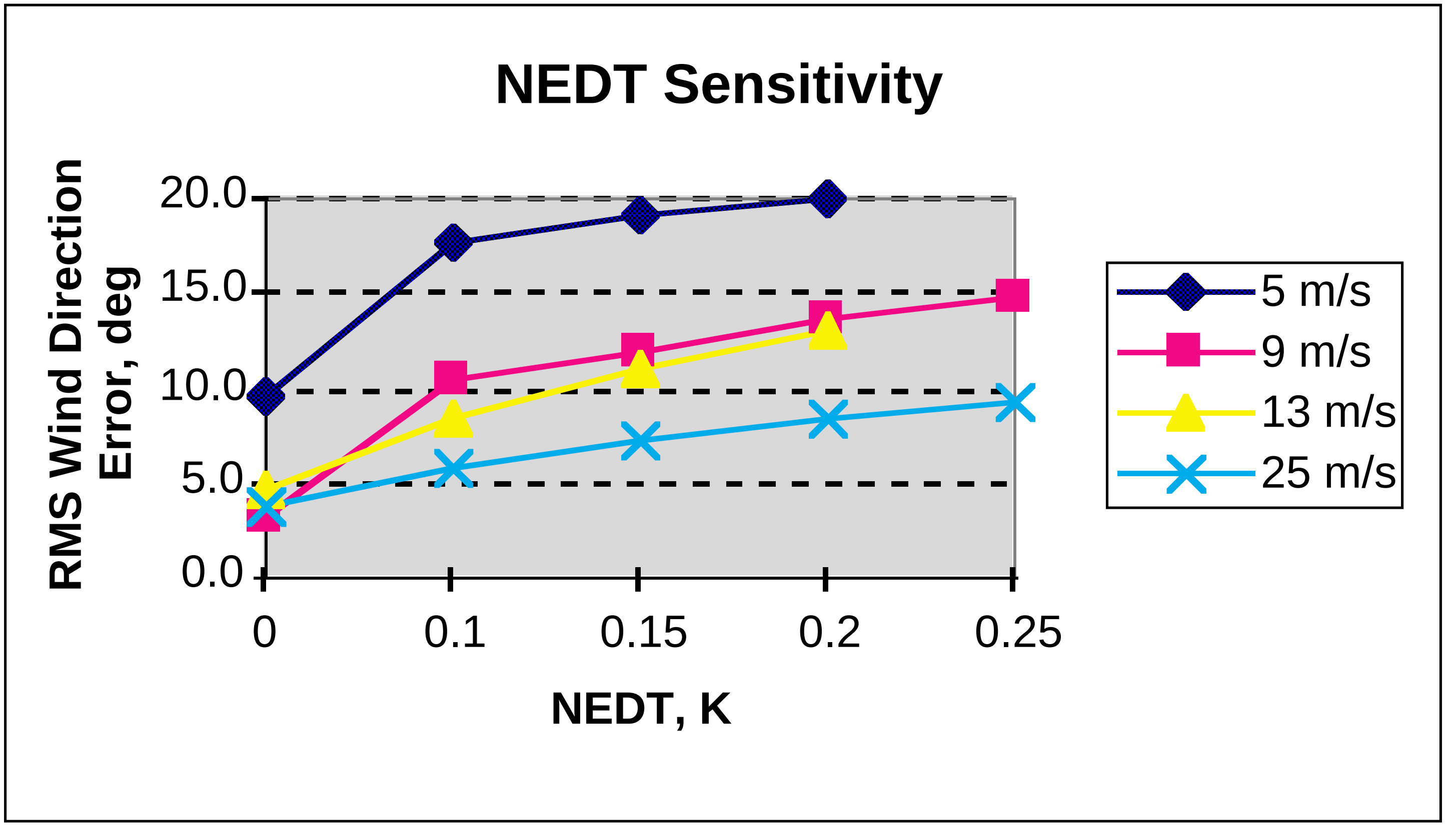
Wind Direction Sensitivity
Polarization Rotation



Wind Direction Sensitivity
Earth Incidence Angle (EIA)

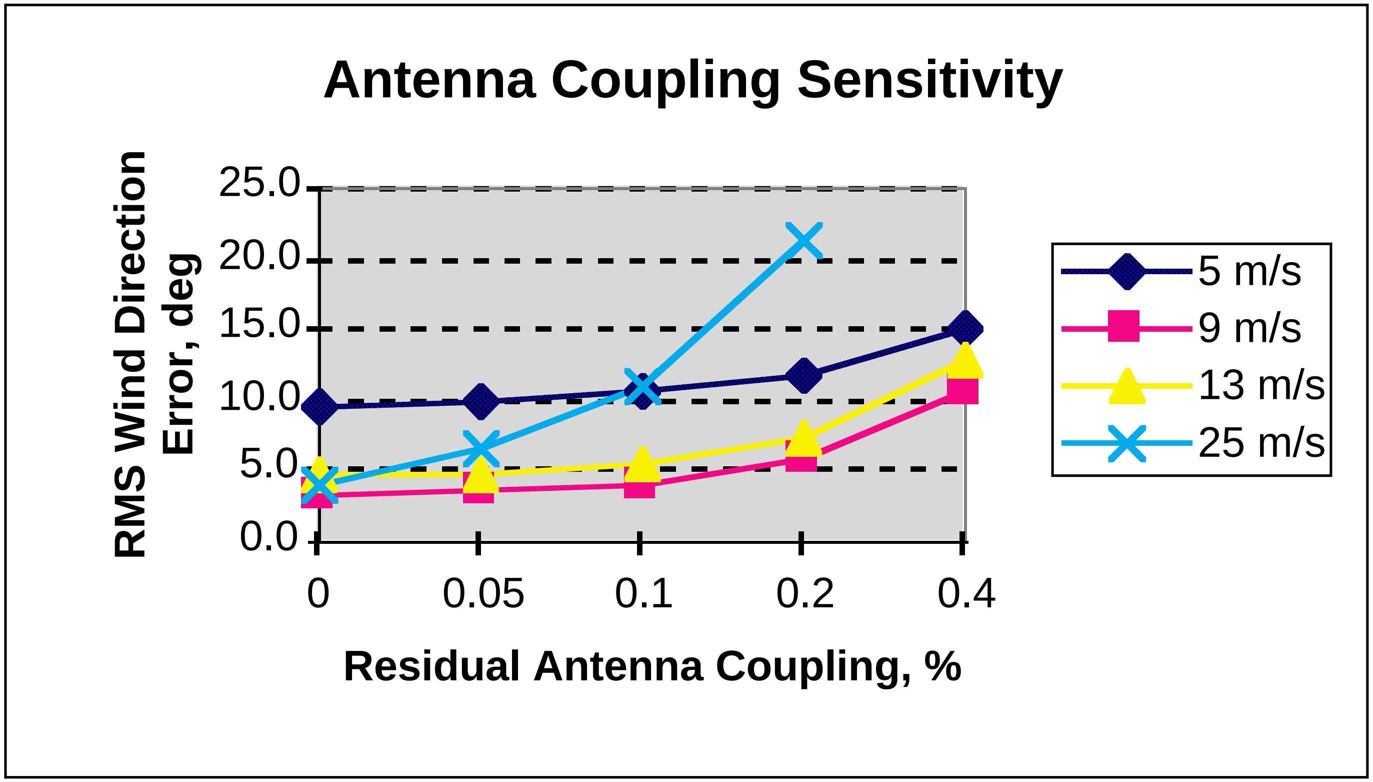


Wind Direction Sensitivity
NEDT - Radiometer Sensitivity



Assumes All Five Frequencies Have Same NEDT

Wind Direction Sensitivity
Antenna Pattern Correction



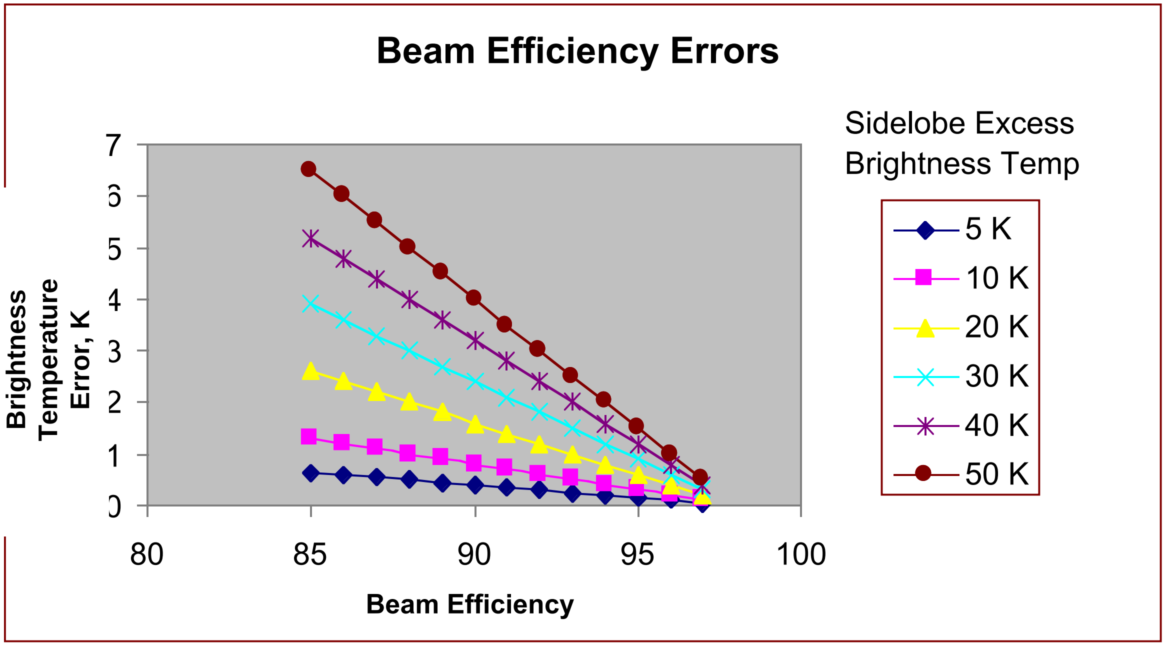
Wind Direction Sensitivity
Receiver/Feed Calibration

Linear Pol Cal Bias, K	Polarimetric Channels Bias, K	Wind Direction Error, deg
0	0	3.2
.5	.1	5.0
.5	.2	5.2
.7	.2	6.3
.7	.3	6.6
.75	.25	6.8
.8	.2	7.0
.8	.25	7.1
.8	.3	7.2

Wind Speed = 9 m/s

Beam Efficiency

- Beam Efficiency Defines Amount of Energy Received From the Main Beam
- Energy Received in the Antenna Sidelobes Is an Error on the Measured Brightness Temperature
- Effect Is Greatest Near Coastlines and Other Large Gradients
- Partial Correction Is Possible Depending on Knowledge of Sidelobe Scene
- WindSat Has Goal of 95% Beam Efficiency to Minimize Errors and Dependence on Unreliable Corrections



Frequency Selection to Meet WindSat Mission Goals

- 10.7, 18.7 and 37.0 Are Fully Polarimetric
  - Aircraft Data Demonstrates Sensitivity to Wind Direction Signal
- 23.8 GHz Provides Water Vapor Correction Channel
- 6.8 GHz Channel Provides Penetration of Heavy Clouds As Well As Sea Surface Temperature Data Needed for Physical Retrieval Algorithm; Assists in Wind Speed Retrieval As Well As Wind Direction

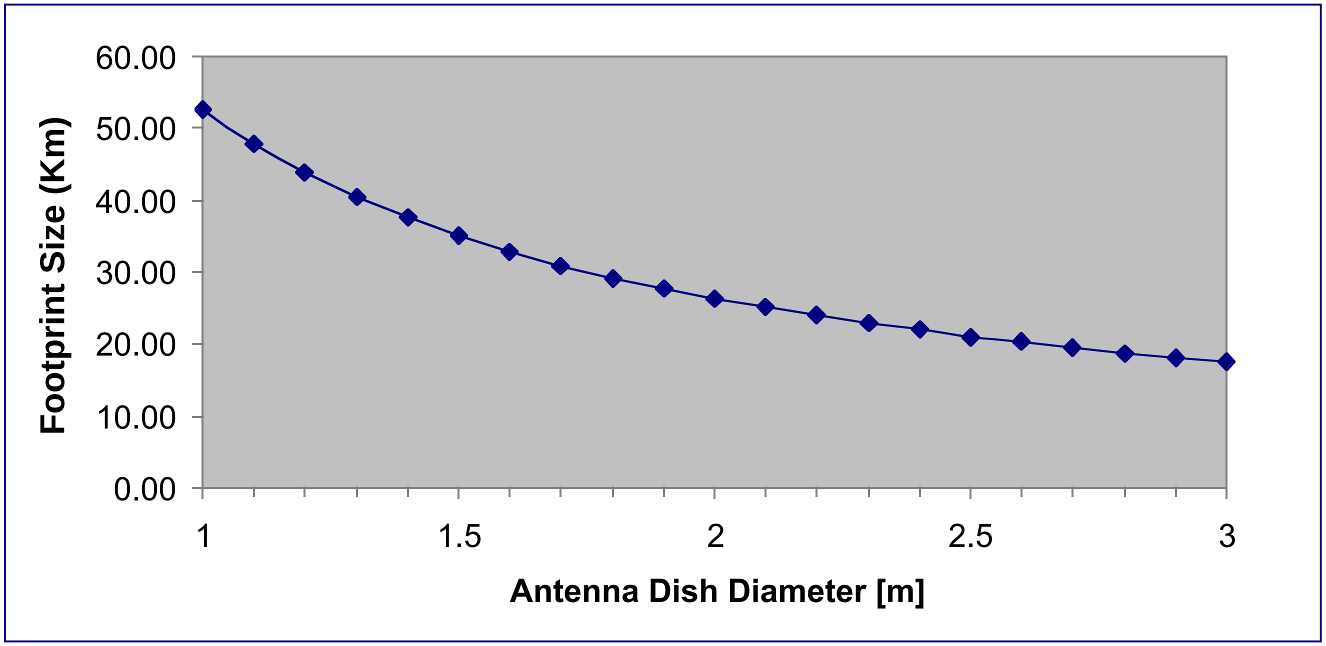
- WindSat Retrieval Performance in Presence of Heavy Clouds (w=9 m/s)
  - 18.7, 23.8, 37 GHz — 26.9° Wind Direction Error
  - 10.7, 18.7, 23.8, 37 GHz — 21.6° Wind Direction Error
  - 6.8, 10.7, 18.7, 23.8, 37 GHz — 17.7° Wind Direction Error

- WindSat Retrieval Performance in No Clouds (w=9 m/s)
  - 18.7, 23.8, 37 GHz — 19.5° Wind Direction Error
  - 10.7, 18.7, 23.8, 37 GHz — 14.7° Wind Direction Error
  - 6.8, 10.7, 18.7, 23.8, 37 GHz — 14.9° Wind Direction Error

Spatial Resolution Constraint

- For a Given Orbit and Scan Angle, Resolution Is Determined by the Primary Reflector Diameter
- WindSat Launch Vehicle Constraints Limits Antenna Aperture to 1.83 m (72 inches)
- Wind Vector Retrieval Will Be Dominated by Highest Three Frequencies Resulting in spatial Resolution of ~30 km

18.7 GHz, 24 dB Taper



WindSat System Requirements and Goals (1)

Radiometer

Freq, GHz	Polarization	BW, MHz	Absolute Accuracy, K*	NEDT, K EFOV	Dynamic Range, K
6.8	V,H	125	0.75/0.25	0.20	3-330
10.7	V,H,U,4	200	0.75/0.25	0.15	3-330
18.7	V,H,U,4	500	0.75/0.25	0.15	3-330
23.8	V,H	500	0.75/0.25	0.20	3-330
37.0	V,H,U,4	2000	0.75/0.25	0.10	3-330

* 0.75 for single receiver channels (e.g., V, H); 0.25 for third and fourth Stokes parameters

Summary of WindSat System Requirements and Goals (2)

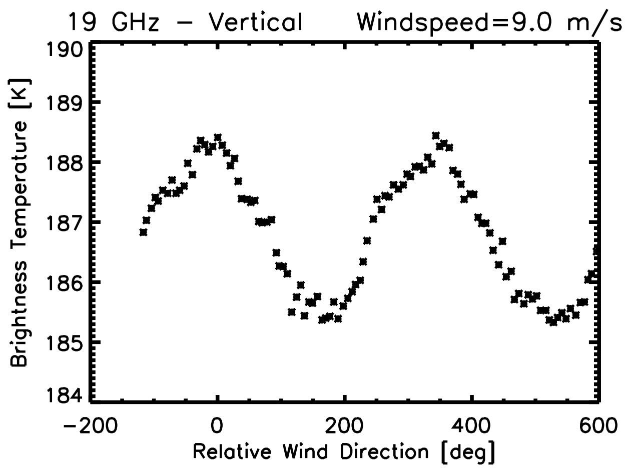
- **Antenna**
  - **Beam Efficiency – 95% for All Frequencies**
  - **Polarization Purity – Maximum Residual Coupling of 30 dB**
  - **Horizontal Resolution – Goal to Achieve Effective Field of View As Close To NPOESS IORD As Possible. Currently ~ 30 km.**
  - **Beam Coincidence – Must Be Able to Overlay Beams With Temporal Re-Registration and Beam Averaging**
  - **Polarization Rotation Angle (PRA)**
    - **Knowledge of <0.05° Bias and Random**
    - **Alignment of ± 1° : Wide Range Acceptable Because of Robust Correction**
  - **Earth Incidence Angle (EIA)**
    - **Nominal Fixed EIA In Range of 50°-55° – Consistent With NPOESS CMIS Concept, Aircraft Data, SSM/I Heritage**
    - **Knowledge of <0.05° Bias and Random**
    - **Maximum Variation of ~0.25°: Maintain Linearity of T_B Variation With EIA**

Summary of WindSat System Requirements and Goals (3)

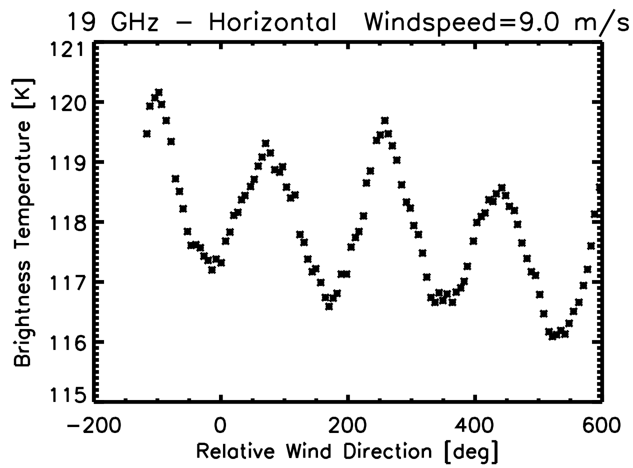
- **Scan/Sampling**
  - **Along Scan – Spatial Nyquist Sampling for All Frequencies**
  - **Along Track – Contiguous Sampling of 37 GHz Pixels; Nyquist Sampling of Lower Frequencies**
  - **Mapping Accuracy – Goal of 4 km (Half of 37 GHz Pixel)**
  - **Scan Azimuth Angle – Control of < 0.15° To Ensure Repeatable Cold Calibration**
  - **Fore and Aft Viewing – Necessary to Compare One-Look and Two-Look Wind Direction Retrieval Performance**
  - **Swath – Maximum Possible Consistent with On-Orbit Calibration Requirements**

Back Up

Aircraft Data, 19 GHz, w = 9 m/s



19v.eps



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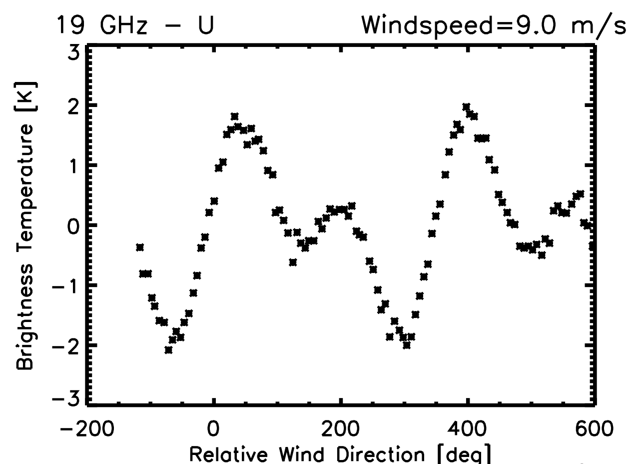
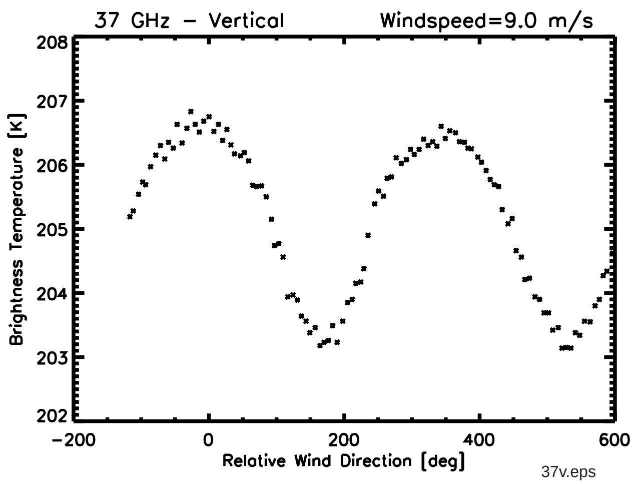


19u.eps

Aircraft Data, 37 GHz, w = 9 m/s



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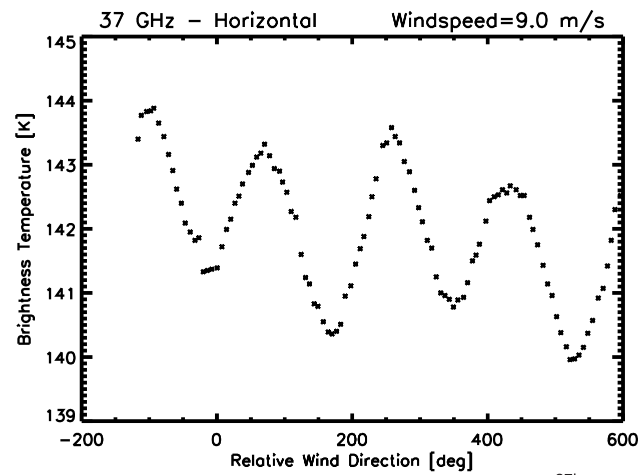

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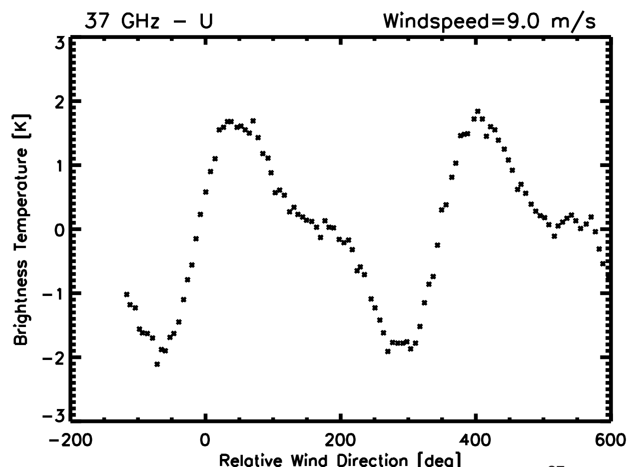


37u.eps

WindSat Mission Operations

T. Barock

Requirements Flow Down

Mission Requirements
(Mission Requirements Document (MRD)

Mission Operation Specification

Operational Requirements
(Mission Operations Plan)

Technical Requirements
(Ground, Flight Operations, Data Product Segment Specification)

Mission Ops Requirements Allocated from MRD

- **Collect Passive Polarimeter Data Globally As the Satellite Orbit Permits**
- **Demonstrate Passive Polarimeter as a Reliable and Cost Effective Means of Measuring Ocean Wind Field Data That Meets Navy and NPOESS Requirements**
- **Validate Sensor Data Algorithms to Demonstrate That Data From This Type of Sensor Can Meet Navy and NPOESS Requirements for Derivation of Wind Speed and Direction As a First Priority; Then, Sea Surface Temperature, Integrated Atmospheric Water Vapor, Cloud Liquid Water, Rain Rate, Sea Ice, and Soil Moisture As Time and Resources Permit**
- **Provide Processed Wind Field Data to Central Sites for Operational Demonstration**
- **Provide Real Time Direct Downlink Capability to Demonstrate the Ability to Provide Tactical Users Access to Unprocessed WindSat Data**
- **Integrate Into NPOESS Phase I Ground Control Architecture**

Mission Ops Overview

Mission Ops

- Pre-Launch
- Post-Launch
- Calibration/Validation
- Operational Demonstration

Satellite

RTS
Remote Tracking Station

SOC
Satellite Operations Center

POC
Payload Operations Center

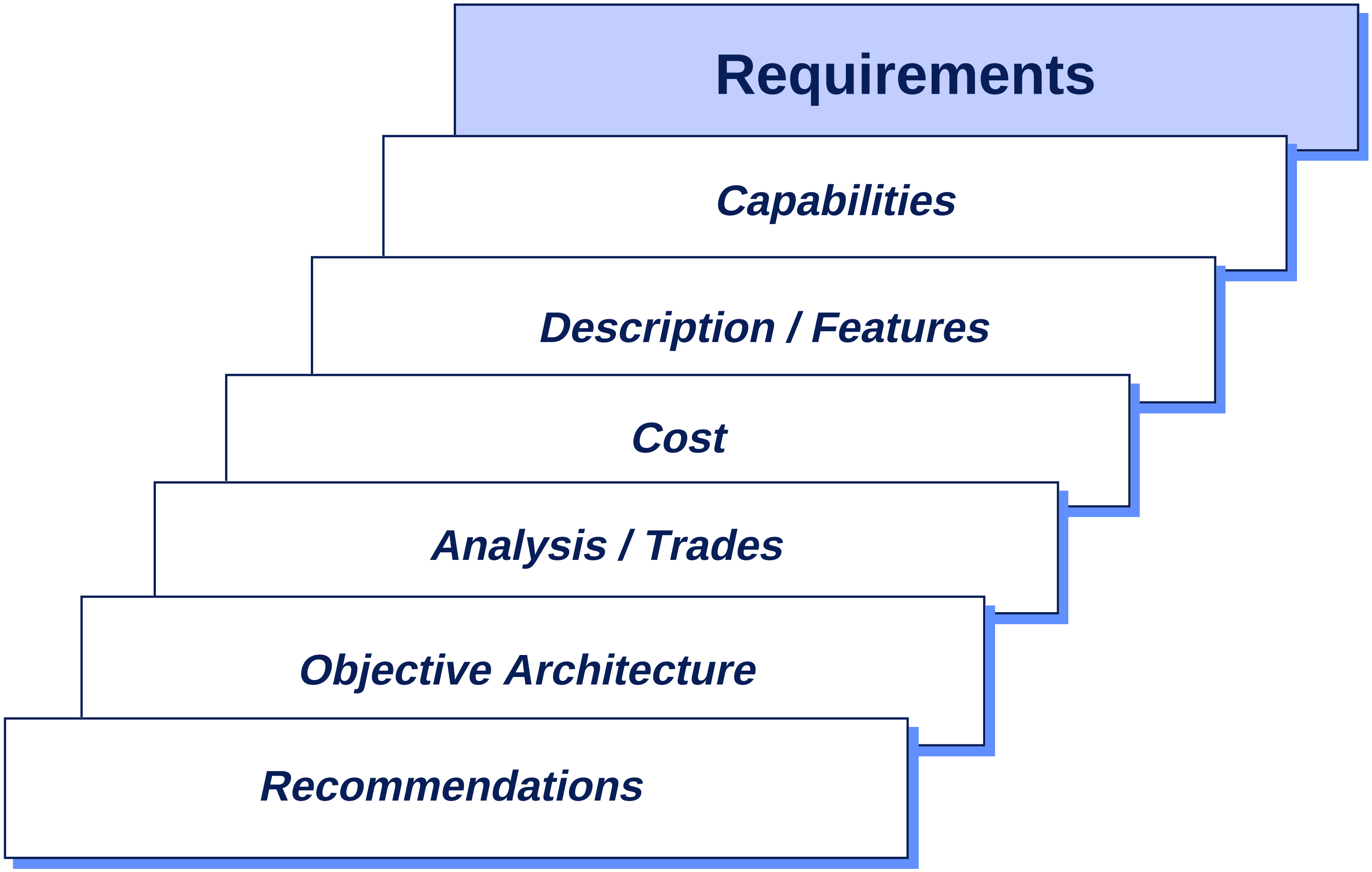
Customer

Allocated Program Requirements

- Mean Mission Duration - 3 Years
- Orbit (TBD)
  - EELV Launch 55 Degree Inclination 850 Km
  - Taurus Launch 98.7 Degree Inclination 830 Km
  - Taurus Alternative
- Launch Vehicle (TBD)
  - Enhanced Expendable Launch Vehicle (EELV), June 2001
- Spacecraft Bus (TBD)
- STP First Year Operations
- Calibration / Validation Will Take 6-12 Months
- Operational Demonstration 24 Months Following Cal/Val
- Tactical Terminals, Tactical Algorithm Development
  (To Be Provided by Tactical Customers)

The Process

- **Mission Ops Development**



Major Mission Functional Areas

Satellite

- Uplink
- Downlink
- Tactical DL
- Data Storage
- Payload Duty Cycle
- Sensor Data Rate

RTS
Remote Tracking Station

- Number of Stations
- Data Buffer Capacity
- Data Take Away Rates
- Uplink/Downlink Format

SOC
Satellite Operations Center

- Mission Planning
- Command and Control
- Launch Coordination
- Spacecraft Initialization
- Sensor Calibration
- Payload Monitoring
- Payload Performance Assessment
- Data Acquisition
- Data Dissemination
- Ground Support Training

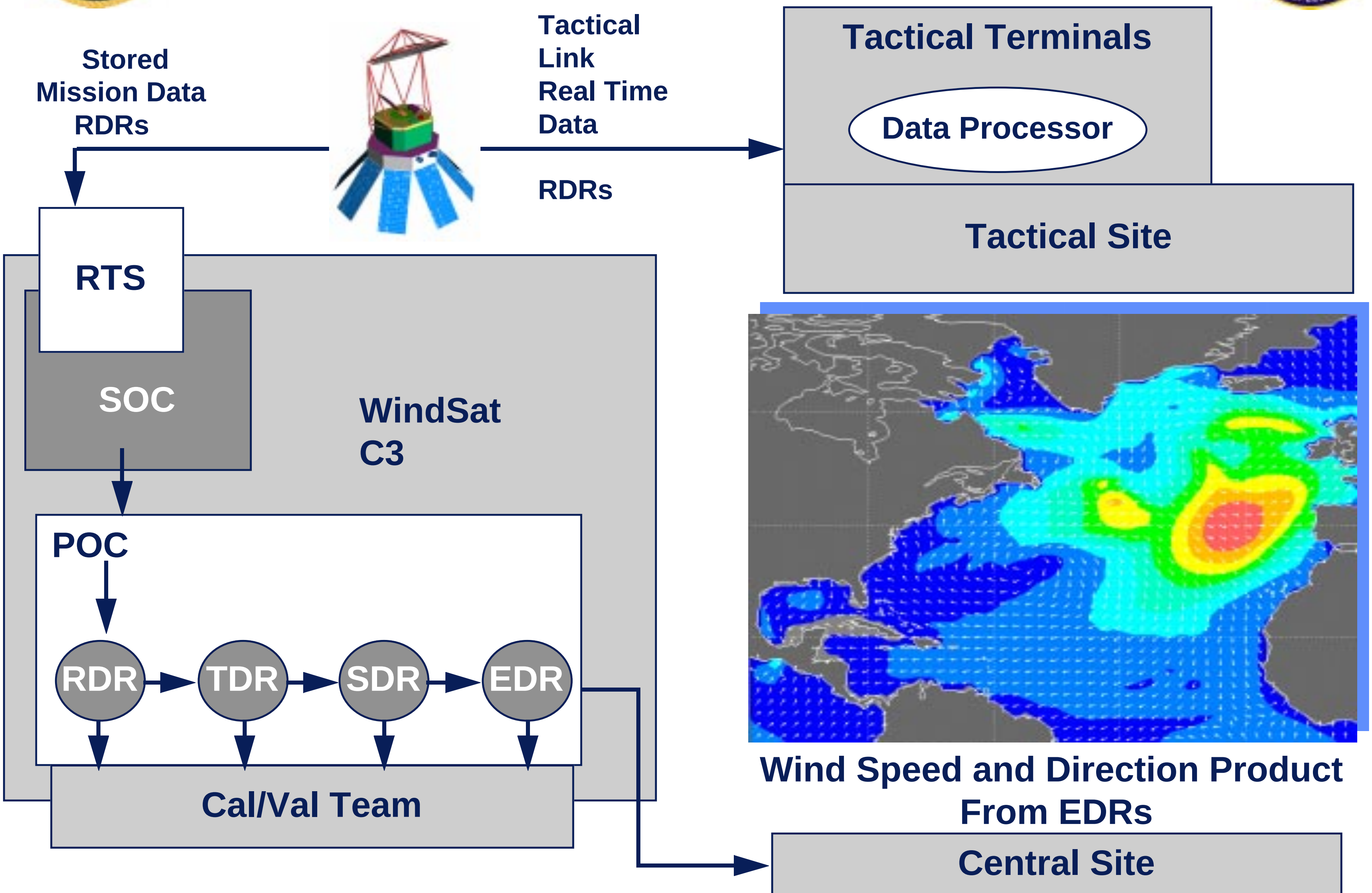
POC

- Data Processing
- Data Archival
- Algorithm Validation

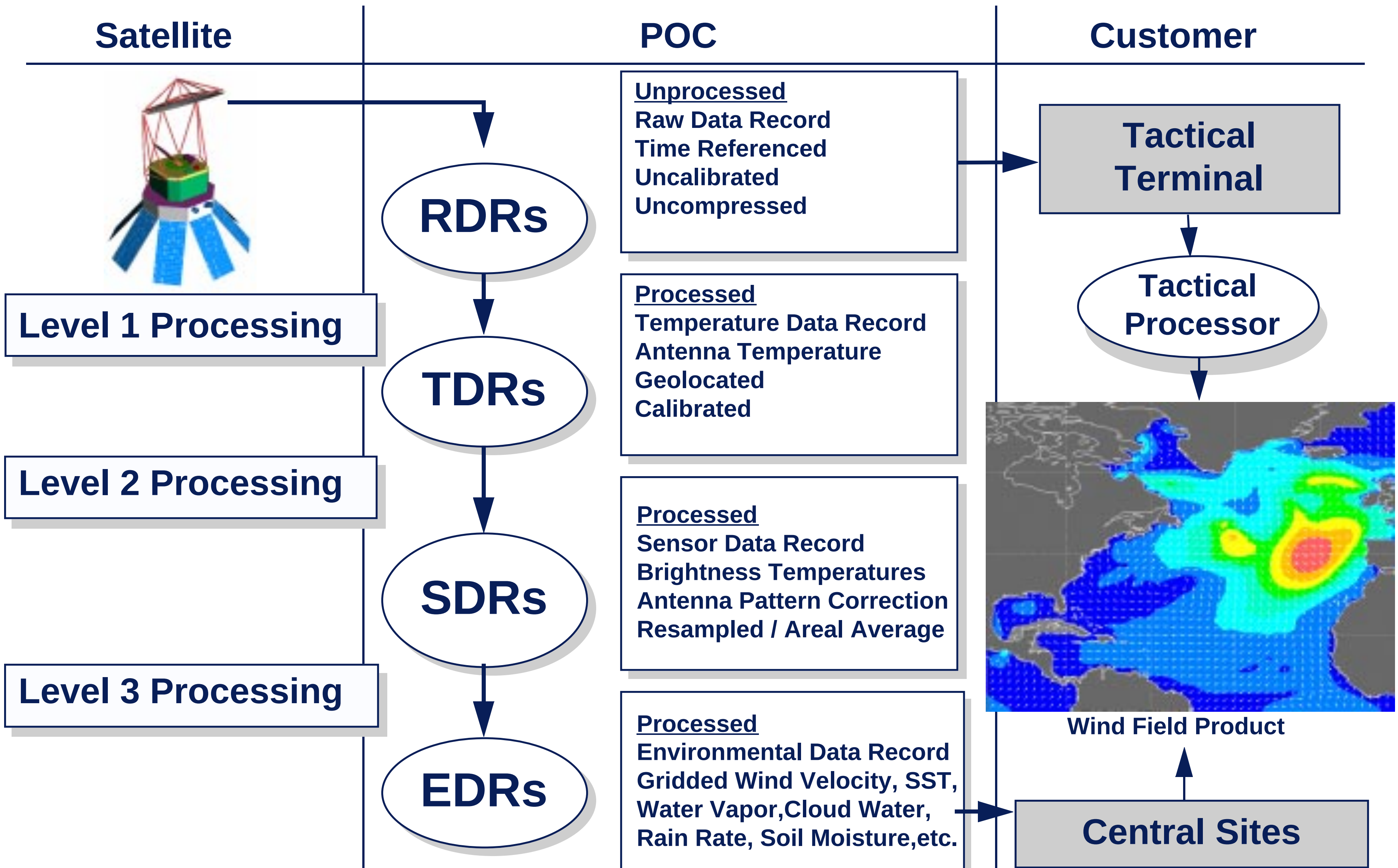
Customer

- *Cal/Val Team*
- *Central Site*
- *Tactical User*

Mission Ops Overview



Mission Data Processing/Data Flow



Mission Ops Requirements Summary (1 of 9)

Element	Requirement	Type	Derived/ Allocated
Program	Collect Satellite Passive Polarimetric Sensor Data Globally as the Orbit Permits	Operational	Allocated
Program	Demonstrate Satellite Passive Polarimetric Technology as a Reliable and Cost Effective Means of Measuring Ocean Wind Field that Meets Navy and NPOESS Requirements	Operational	Allocated
Program	Validate Wind Algorithms; Validate Other Algorithms as Time and Resources Permit	Operational	Allocated
Program	Provide Processed Wind Field Data to Central Sites for Operational Demonstration	Operational	Allocated
Program	Provide Real Time Direct Downlink to Tactical Users for Operational Demonstration	Operational	Allocated
Program	Integrate into NPOESS Phase I Ground Architecture	Operational	Allocated

Mission Ops Requirements Summary (2 of 9)

Element	Requirement	Type	Derived/ Allocated
Mission	Orbit (TBD) : (98.7° Degrees 830 Km Optimum Based on Taurus), (55 Degree 850 Km Based on EELV) NODAL Crossing Time (TBD)	Operational	Allocated
Mission	Satellite On-Orbit Life: 3 Years	Operational	Allocated
Mission	Sensor Data Timeliness (1.25 x Period + 30 min) for Polar Orbit; Non-Polar (TBD)	Operational	Allocated
Mission	Sensor Data Processing Time RDX-EDR (TBD)	Operational	Derived
Mission	Sensor Data Latency (Cumulative Storage and Transmission Time)	Operational	Derived
Mission	Sensor Data Freshness (Timeliness + Latency) (TBD)	Operational	Derived
Mission	Encrypted Satellite Comm Links (Waiver on DL)	Operational	Allocated
Mission	Validate Wind Algorithm: First 6 –12 months -	Operational	Allocated
Mission	Validate Other Algorithms: (TBD)	Operational	Allocated
Mission	Tactical Wind Algorithm (NRL Will Furnish Validated Wind Algorithm, Services Provide Development and Integration of Algorithm into Tactical Terminal(s)	Operational	Derived
Mission	Launch Support at Launch Site (Weather, UL/Winds, Range Status)	Operational	Derived
Mission	Operations Management Structure	Operational	Derived
Mission	Sensor Calibration Plan (TBD)	Operational	Derived

Mission Ops Requirements Summary (3 of 9)

Element	Requirement	Type	Derived/ Allocated
Satellite	Up Link (Command & Control) (2 Kbps)	Technical	Allocated
Satellite	Downlink (Satellite Health & Status) (20 Kbps)	Technical	Allocated
Satellite	Downlink (Payload Data, Store & Forward) (2.53 Mbps)	Technical	Allocated
Satellite	Downlink (Tactical Real Time Data) (196 Kbps)	Technical	Allocated
Satellite	Link Budgets (TBD)	Technical	Derived
Satellite	Bit Error Rates (10-6 Notional)	Technical	Derived
Satellite	Calibration of Polarimeter: Initial: 30 Days. Updated as Necessary Throughout Mission	Operational	Allocated
Satellite	Payload Duty Cycle (100% Over Ocean)	Operational	Allocated
Satellite	Payload Sensor Data Collection Rate (174 Kbps)	Technical	Allocated
Satellite	Payload Sensor Data Format (TBD) Recommend Modified SSM/I Specification	Technical	Allocated
Satellite	Secondary Payloads Data Collection Rate (TBD)	Technical	Allocated
Satellite	Payload(s) Data Storage Capacity (TBD)	Technical	Derived
Satellite	Command Upload Volume (TBD)	Technical	Derived
Satellite	Store and Dump Sized to Prevent Memory Overwrites	Operational	Allocated
Satellite	Telemetry Download Volume (TBD)	Technical	Derived
Satellite	Satellite Position f(Time) With Precision (200 meters)	Technical	Allocated

Mission Ops Requirements Summary (4 of 9)

Element	Requirement	Type	Derived/ Allocated
SOC	**Mission Operations Plan (Document)**	**Operational**	**Derived**
SOC	**Mission Planning (Bus and Payload)**	**Operational**	**Derived**
SOC	POC/SOC Communication, Coordination and Interface	Operational	Derived
	Satellite Simulator	Operational	Derived
SOC	**Mission Scheduling (Bus and Payload)**	**Operational**	**Derived**
SOC	**Mission Execution (Bus and Payload)**	**Operational**	**Derived**
	Command Verification		
SOC	**Mission Data Handling (Bus and Payload)**	**Operational**	**Derived**
SOC	**Launch Coordination**	**Operational**	**Derived**
SOC	Pre-Launch Check-Out: (RTS, Comm Interfaces)	Operational	Derived

Mission Ops Requirements Summary (5 of 9)

Element	Requirement	Type	Derived/ Allocated
SOC	**Spacecraft Initialization**	**Operational**	**Derived**
SOC	Post-Launch Initialization:	Operational	Derived
SOC	S/C Acquisition (State Vector, Orbital Elements)	Operational	Derived
SOC	S/C Orientation	Operational	Derived
SOC	S/C Stabilization	Operational	Derived
SOC	S/C Power-up	Operational	Derived
SOC	S/C Telemetry	Operational	Derived
SOC	**Engineering Evaluation**	**Operational**	**Derived**
SOC	Post-Launch Check-out: All Systems and Payloads	Operational	Derived
SOC	Initial Satellite Performance Assessment	Operational	Derived
SOC	**Payload Monitoring**	**Operational**	**Derived**
SOC	Sensor Stability	Technical	Derived
SOC	Sensor Noise (NEDT)	Technical	Derived
SOC	Sensor Orientation (Pointing Knowledge in Time)	Technical	Derived

Mission Ops Requirements Summary (6 of 9)

Element	Requirement	Type	Derived/ Allocated
SOC	**Satellite Performance Assessment**	**Operational**	**Derived**
SOC	Satellite System Performance Trending (Payload, Health and Status)	Operational	Derived
SOC	Monitor GO/NO GO System Performance Thresholds	Operational	Derived
SOC	**Mission Ops Plan**	**Operational**	**Derived**
SOC	Normal Procedures (Pre-Launch through Operational Demonstration)	Operational	Derived
SOC	On- Orbit Anomalies	Operational	Derived

Mission Ops Requirements Summary (7 of 9)

Element	Requirement	Type	Derived/ Allocated
POC	**Data Processing**	**Operational**	**Derived**
POC	Processing Time (RDR to EDR)	Operational	Derived
POC	Sensor Data Quality (Fidelity)	Operational	Derived
		Operational	Derived
POC	**Data Dissemination**	**Operational**	**Derived**
POC	Dissemination Time (TBD)	Technical	Derived
POC	Bit Error Rate (10^{-6})	Technical	Derived
POC	**Data Archive**	**Operational**	**Derived**
POC	Data Types: (RDR, TDR, SDR, EDR)	Operational	Derived
POC	Data Format (RDR, TDR, SDR, EDR)	Operational	Derived
POC	Data Accessibility	Operational	Derived
POC	Data Requests	Operational	Derived
POC	Data Volume (3 Year Mission)	Operational	Derived

Mission Ops Requirements Summary (8 of 9)

Element	Requirement	Type	Derived/ Allocated
POC	**Algorithm Validation**	**Operational**	**Derived**
	Algorithm Validation Plan		

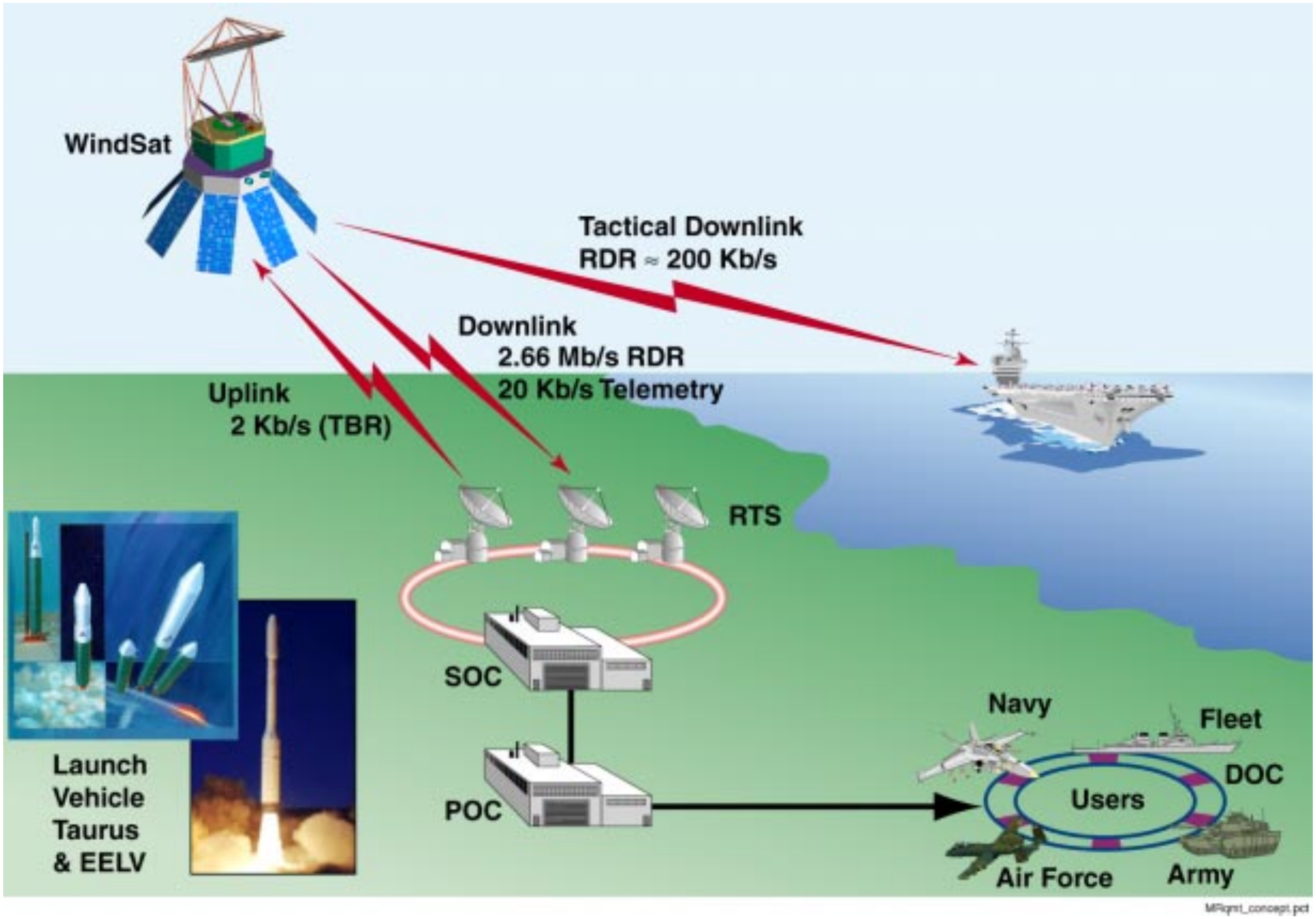
Mission Ops Requirements Summary (9 of 9)

Element	Requirement	Type	Derived/ Allocated
Customer	Cal/Val Team	Technical	Derived
	Perform Wind Algorithm Validation	Technical	Derived
	Perform Validation of Secondary Algorithms As Required	Technical	Derived
Customer	Central Site	Operational	Derived
	Receive Processed WindSat Data (EDR’s)	Operational	Derived
	Apply WindSat EDR’s to Selected Products	Operational	Derived
Customer	Tactical Receivers	Operational	Derived
	Tactical Processor	Operational	Derived
	Tactical Algorithm Development and Integration	Operational	Derived

Mission Ops Development: Steps in Process

- Requirements
- Capabilities Survey
  - Reference Documents
  - Site Visits - NESDIS SOC/CDA, STP/TEO/AFSCN, NAVSOC, Blossom Point, NASA
- Description/Features
  - Mission Requirements Document
  - Interface Control Documentation
- Cost
  - ROM Estimates Life Cycle Cost; Recurring, Non Recurring
- Analysis/Trades
  - RTS Accessibility, Number of Stations, Solid State Storage
  - Link Analysis S/X Band
- Objective Architecture
- Recommendations

Notional Ground Segment



Issues and Concerns

- Satellite Bus (Decision)
  - Communication Interfaces
  - Mission Data Storage Capacity
- Launch Vehicle (Decision)
  - Per Orbit, RTS Accessibility, On Board Storage
  - 55° Inclination Orbit, RTS Accessibility, On Board Storage
- Tactical Algorithm Development and Integration (POM)

Backup Slides

Mission Ops: Guiding Principles

- **Develop Mission Operations That Make the Best Use of Existing or Anticipated C3 Infrastructure**

- **Mirror the Data Pathways Used Operationally for the Special Sensor Microwave Imager (SSM/I) If Possible**

- **Calibration/Validation (Cal/Val) Effort Should Involve the Operational Community to Assure a Seamless Transition and Confidence in the Data**

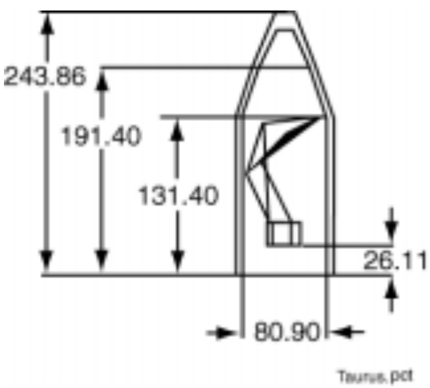
Systems Environments Analysis and Trades

Koss

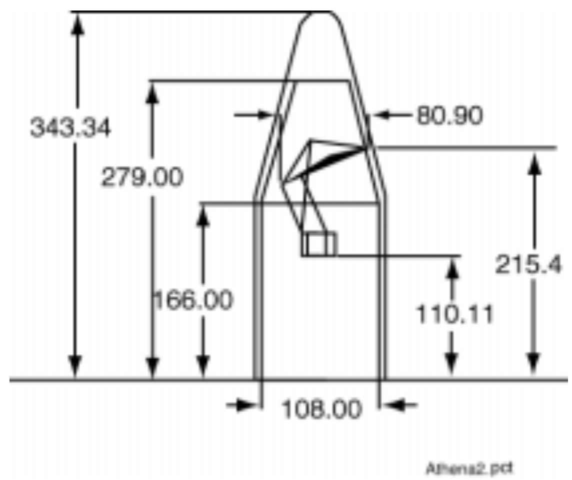
Launch Vehicle Trades

- Launch Vehicle Requirement: Capability to Insert WindSat / Secondary Experiments and Spacecraft Into 850km X 850km X 55° Orbit (EELV/MLV) or 830km X 830km X 98.7° (Sun-Synch) Orbit (Taurus or Athena 2/LMLV2)
- Launch Vehicle Performance
  - Taurus (Orion 38, 92 Inch Fairing, VAFB) ≈ 1300 lb Throw Weight (≈ $25M)
  - Athena 2 (120 Series Fairing, VAFB) ≈ 1700 lb Throw Weight (≈ $25M)
    - 120 Series Fairing Not Production: $1.2M Recurring, $6M Non-Recurring Development (Know by 1/98 If Customer for 120 Series)
  - EELV/MLV (Std Fairing, CCAS≈ 12,000 + lb Throw Weight)
- Mass Available for Spacecraft and Secondary Experiments
  - (WindSat Current Weight Estimate = 347 lb + 30% Margin = 451 lb)
  - Taurus = 849 lb for Spacecraft and Secondary Experiments
  - Athena 2 = 1,249 lb for Spacecraft and Secondary Experiments
  - EELV/MLV = 11,549 + lb for Spacecraft and Secondary Experiments
- Good Mass Margin for Spacecraft / Secondary Experiments Exists
  - *Except Taurus*

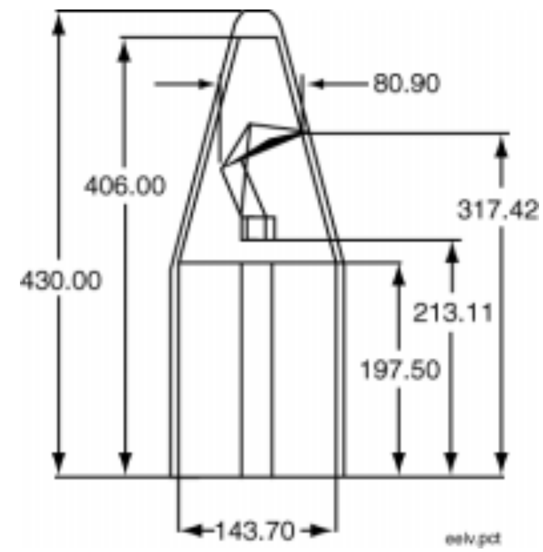
Launch Vehicle Trades
Fairing Comparisons



Taurus



Athena 2



EELV/MLV

- **Taurus Has Very Limited Space for Spacecraft / Secondary Experiments**

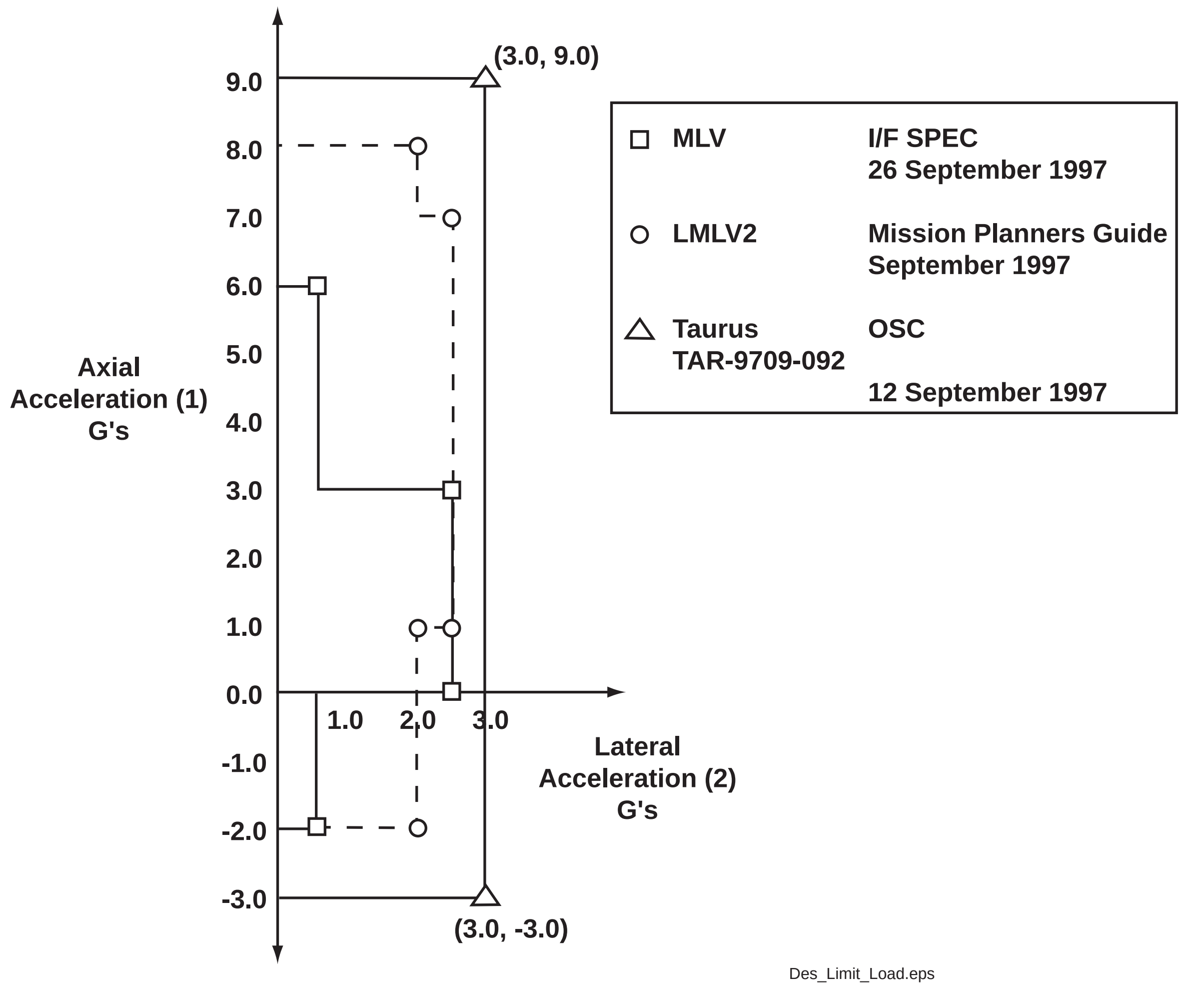
Launch Vehicle Selection

- **Keeping Taurus LV As an Option Drives / Constrains**
  - **Spacecraft Bus Size / Configuration**
  - **Reflector Support Structure Layout**
  - **Cold Cal Source Size and Layout**
  - **Reflector / Dish Size and Feed Layout (e.g., Performance)**
  - **Secondary Experiment Integration**
  - **Eliminates Ability for Additional Spacecraft Launches in Same Fairing**
    - **Ride Sharing on Athena 2 Could Dramatically Lower Price of WindSat**

Structural Design Requirements
Spacecraft / Payload Design Loads

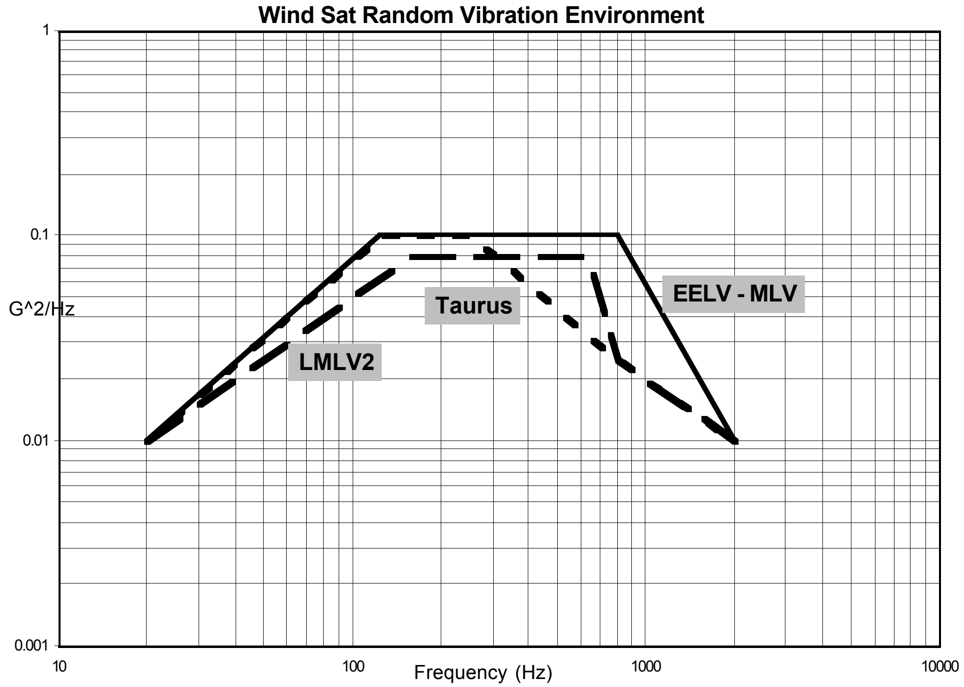
- Quasi-Static Design Limit Loads (Next Page)
  - Based on LV User's Guides
  - Used for Preliminary Design
  - Loads of All LV's Are Enveloped
- Resonant Burn Dynamic Loads
  - Characteristic of Castor 120 SRMs (Taurus and Athena 2)
    - Behaves Like an Axial Sine Sweep
    - 45 - 75 Hz Range
    - Can Couple Into Spacecraft Modes
- Coupled Loads
  - Combined Spacecraft / Payload / Launch Vehicle Models
  - Verifies (Modifies) Quasi-Static Loads

Spacecraft Quasi-Static Design Limit Loads



(1) Plus Acceleration Means SC/LV Interface Compression
(2) Any Lateral Direction

Structural Design Requirements
Random Vibration Environment

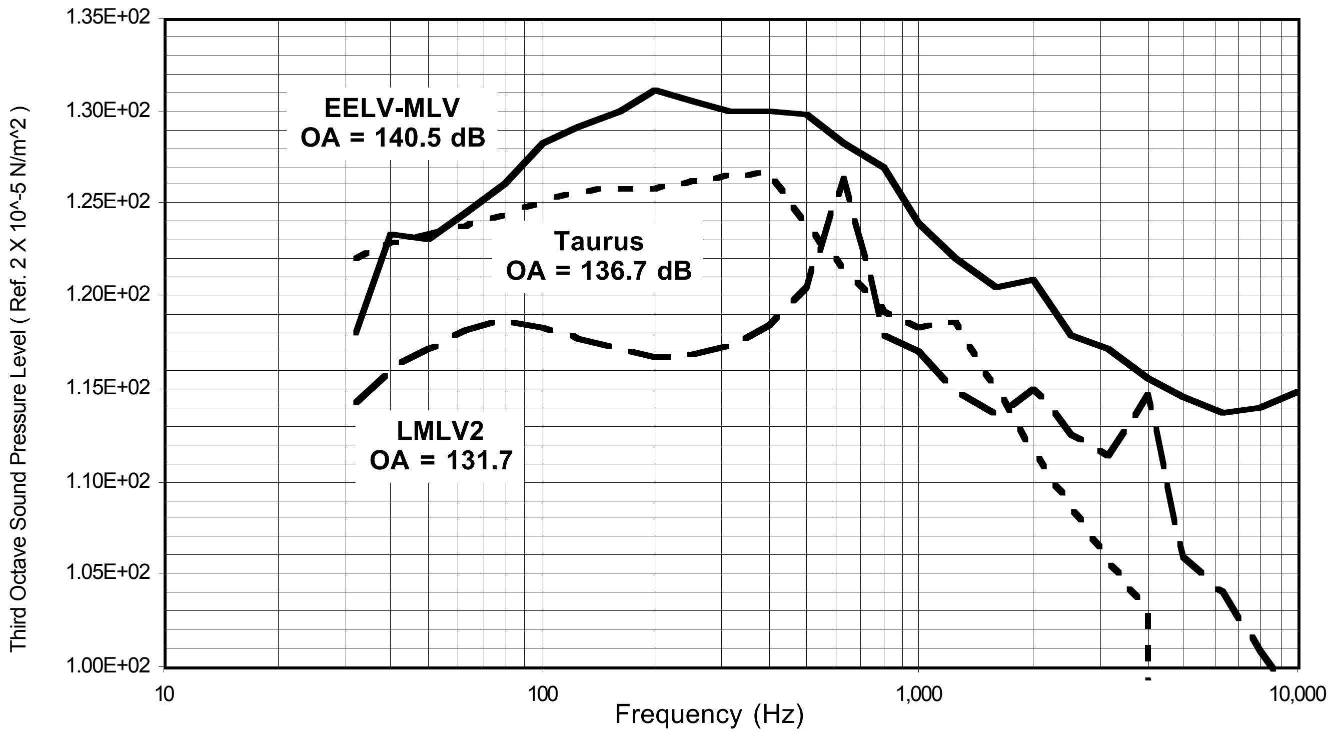


Comparison of Component Random Vibration Environments As Derived from EELV, Taurus & LMLV2 Acoustics

Flight Environment

Frequency (Hz)	EELV - MLV G^2/Hz	Taurus G^2/Hz	LMLV2 G^2/Hz
20	0.01	0.01	0.01
125	0.1	0.1	0.062
160	0.1	0.1	0.08
250	0.1	0.1	0.08
630	0.1	0.033	0.08
800	0.1	0.025	0.025
2000.0	0.01	0.01	0.01
	10.6 Grms OA	8.0 Grms OA	8.4 Grms OA

Structural Design Requirements
Acoustic Environment



WindSat Flight Acoustic Environment
Comparison of EELV, Taurus and LMLV2

Structural Design Requirements
Spacecraft Modal Requirements

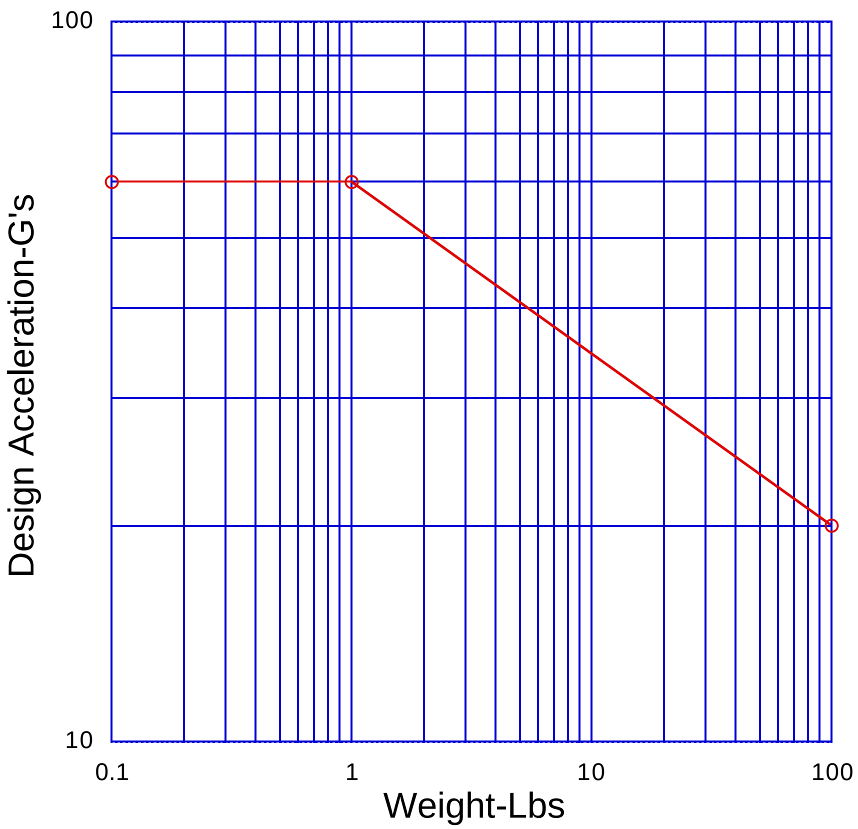
- Modal Requirements Based on LV User's Guides
  - Requirements of All LVs Are Considered
- Axial Modes
  - Only Common Safe Range: 35 - 45 Hz
  - Not a Practical Requirement
  - Difficult to Tune Primary Modes This Close
  - Need to Select LV Early in Design Phase
- Lateral Modes
  - > 20 Hz
    - Difficult to Apply to Secondary Structure
      - (Reflector Support Structure)

Structural Design Requirements
Component Design Loads

- **Mass-Acceleration Curve (MAC)**
  - **Acceleration Is a Function of Weight**
  - **Covers Combined Quasi-Static and Vibro-Acoustic**
  - **Three Axes**
    - **One Axis at a Time**
  - **Design Limit Loads**
    - **Test Loads Increased by 1.25 Test Factor**
  - **This Curve Is Applied to Components, Brackets, and Attachments**

Structural Design Requirements
Component Design Loads

WindSat Mass-Acceleration Curve (MAC)



Design Acceleration Philosophy

- For Designated Components, the Acceleration Level From This Curve May Also Be Used for Random Vibration Test Spectrum Tailoring
- Apply in Three Axes - One Axis at a Time
- Used for Static Design of Components and Their Attachment

Radiation Environment Design Requirements

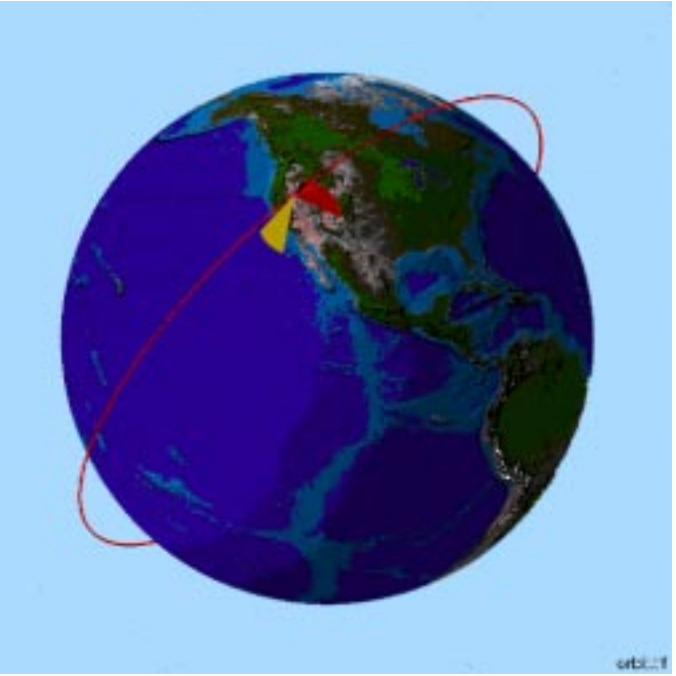
- **Total Dose**
  - **WindSat Parts Will Be Selected Such That No Unacceptable Performance Degradation Occurs Under a 20 kRad Dose**
    - **3 Year Duration**
    - **Based Upon Analyses Behind Spherical 100 mil Aluminum Shielding**
    - **During Solar Maximum**
    - **Using the Worst Case Environment of a Polar Orbit**
    - **Includes a 60% Margin**
- **Single Event Effects**
  - **WindSat Hardware and Software Will Be Designed for Event Tolerance (i.e., Parts Selection, Majority Voting, Where Feasible, Given Program Constraints)**

Orbit Selection

Kelm

Orbit Selection

- Orbit Selected to Be 850 Km Circular Orbit at 55° Inclination
- Selected to Be Near the Operational Orbit of NPOESS/DMSP at 830 Km and Preferred Not to Have Repeat Ground Tracks
- Longitude of Ascending Node Shifts by 138 Km West Each Day
- Overflys Every Available Point in 8 Days

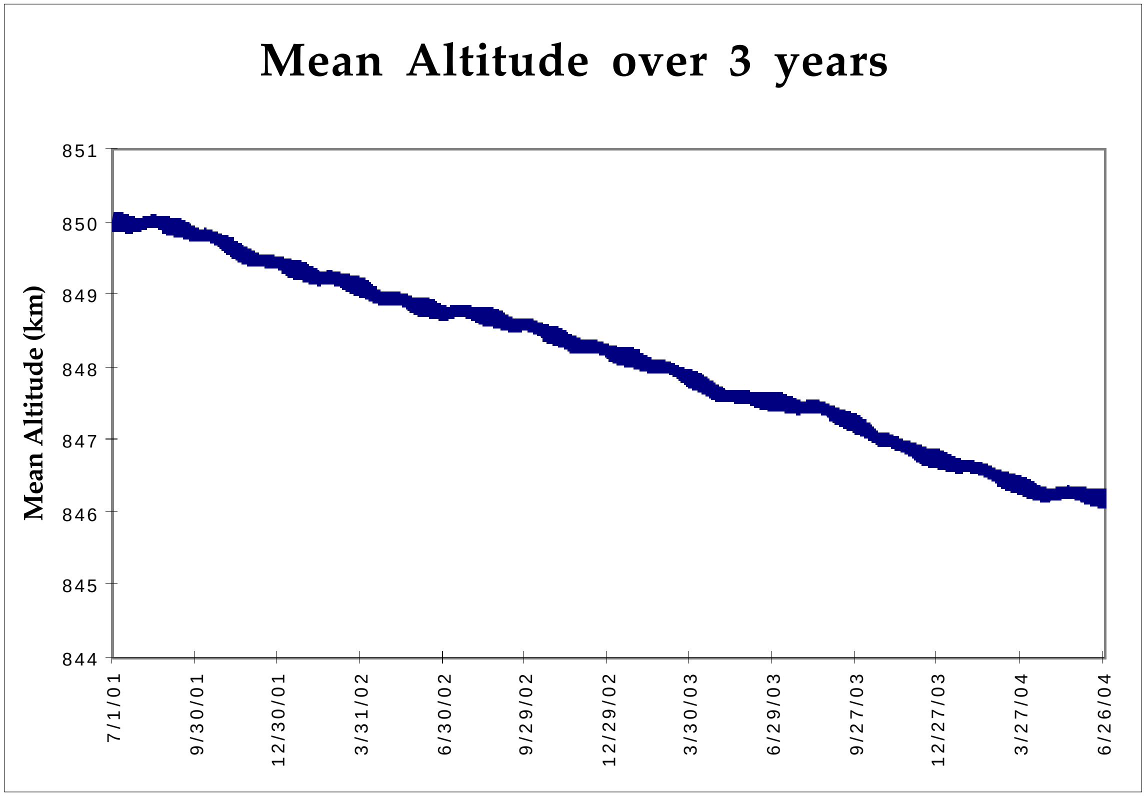


Long Term Orbit Behavior

- Propagated 850 Km @ 55° Circular Orbit Over 3 Year Life With High Fidelity Orbit Propagator
  - 18x18 Gravity Model
  - Lunar and Solar Gravitational Forces Included
  - Drag With C_D = 2.0, Area = 6.76, Mass = M^2, Mass = 456 kg
- Orbit Decay Due to Drag Is Minimal
  - Less Than 4 Km Decay in Average Semi-Major Axis Over 3 Yrs
- Inclination Change Also Minimal, Less Than ±0.005°
- Eccentricity Is Periodic
  - Maximum Eccentricity During Cycle Is 0.0026
  - Period of Cycle Is Approximately a Half Year
  - Maximum Eccentricity of ~ 0.0026 Introduces ~ 37 Km Net Difference in Apogee and Perigee Altitudes

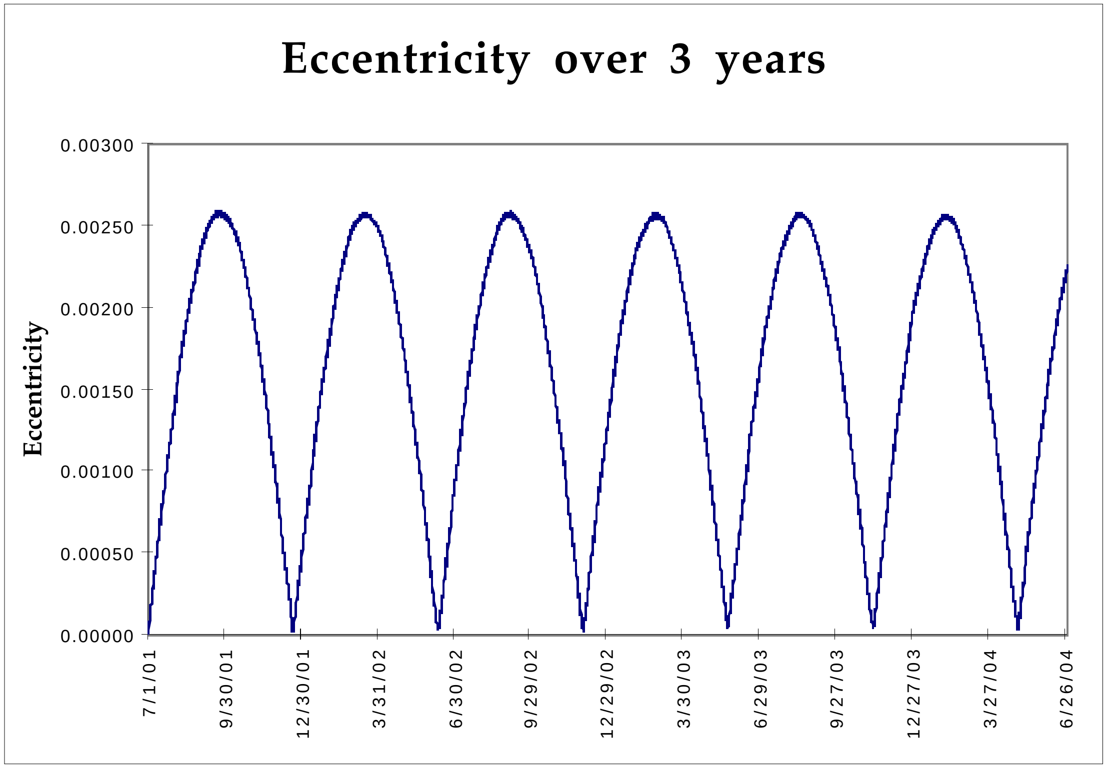
Orbit Decay Due to Drag

- **Orbital Decay Is Less Than 4 Kilometers Over 3 Years**



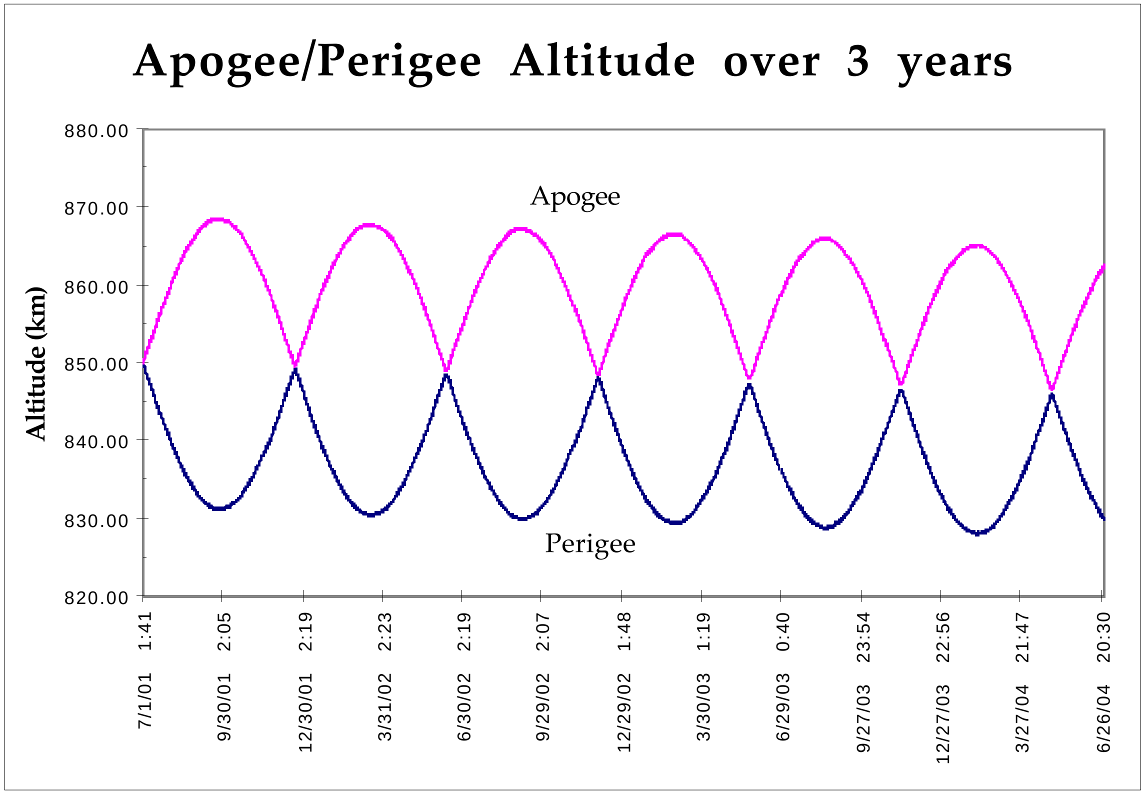
Long Term Change in Eccentricity

- Maximum Eccentricity Is ~0.0026
- Period of Cycle Is ~172 Days
- Eccentricity Could Be Controlled If Necessary

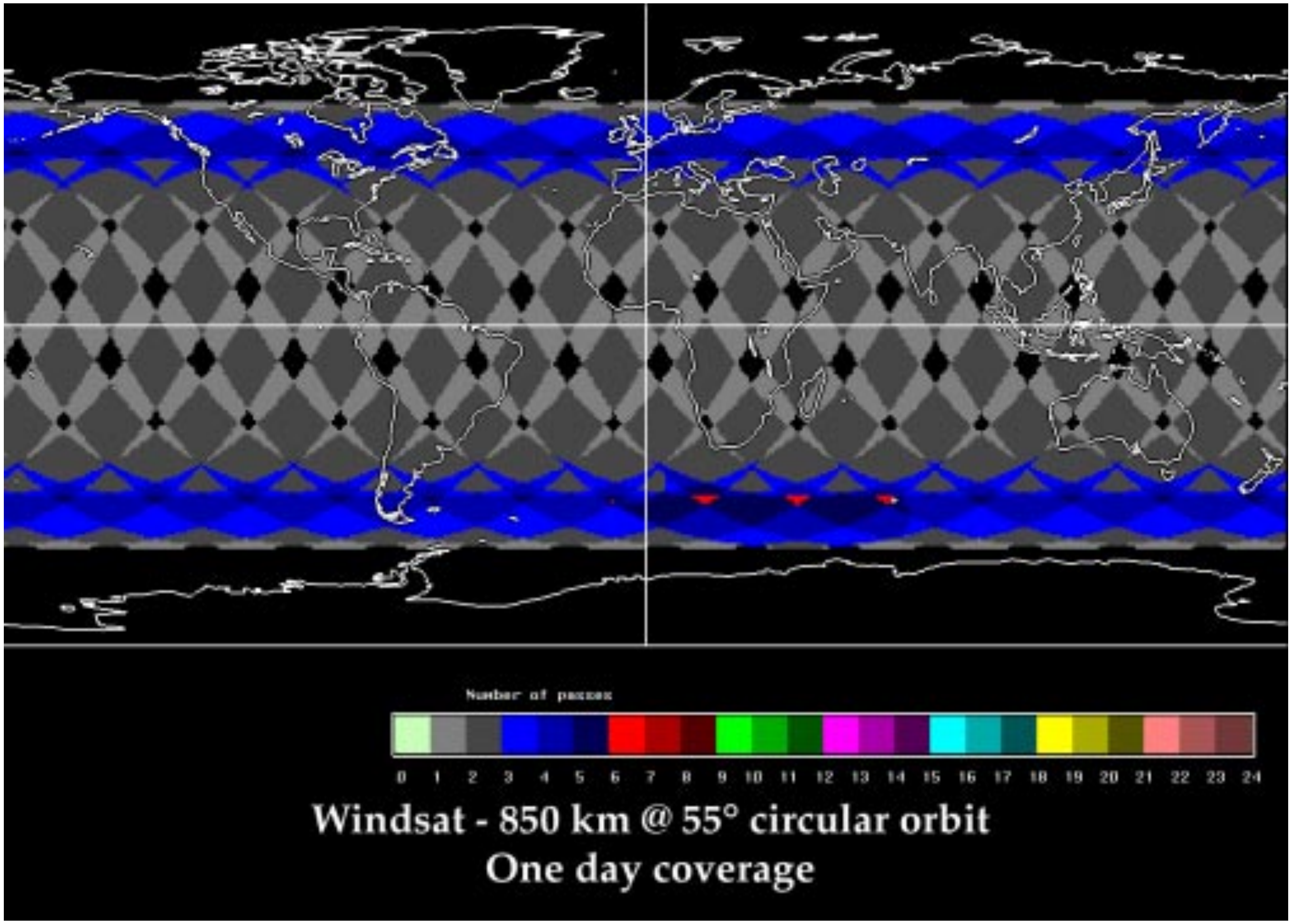


Long Term Perigee/Apogee Altitudes

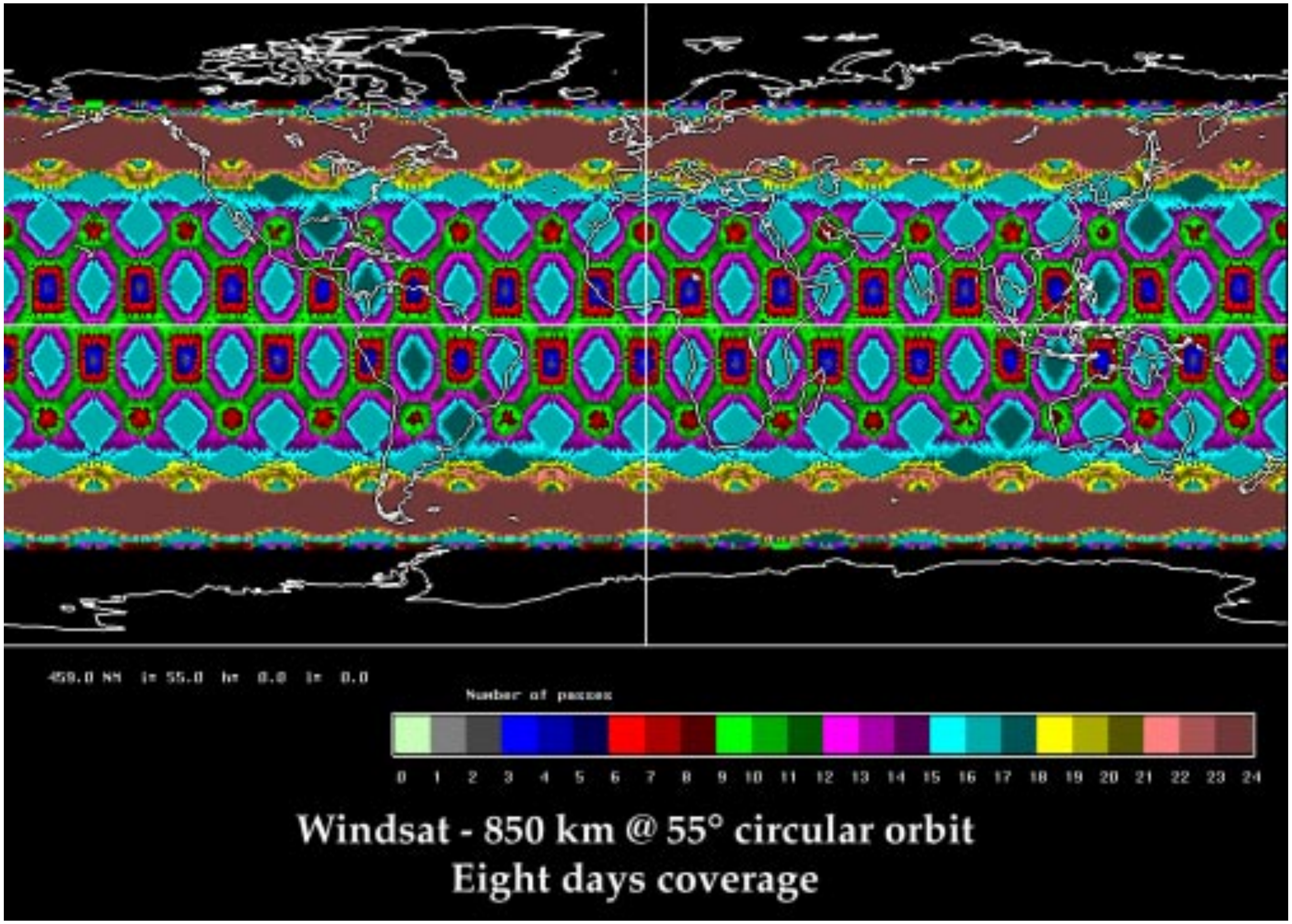
- **Periodic Changes in Eccentricity Introduce Perigee/Apogee Cycle**
- **Largest Difference in Altitude Between Perigee and Apogee Is ~37 Km**



Ground Covered in 1 Day - 55° Inclination



Ground Covered in 8 Days - 55° Inclination

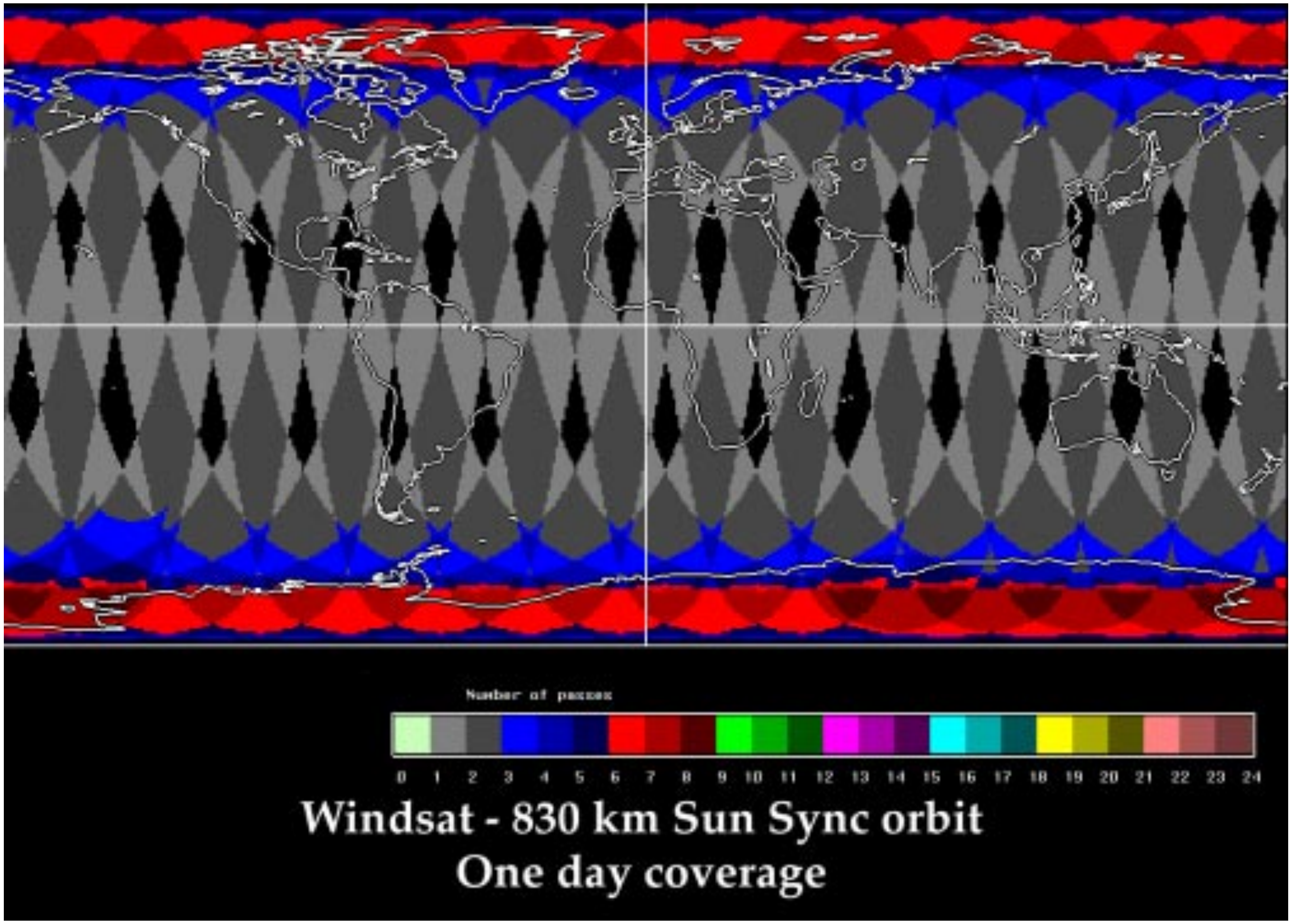


Orbit Insertion Error

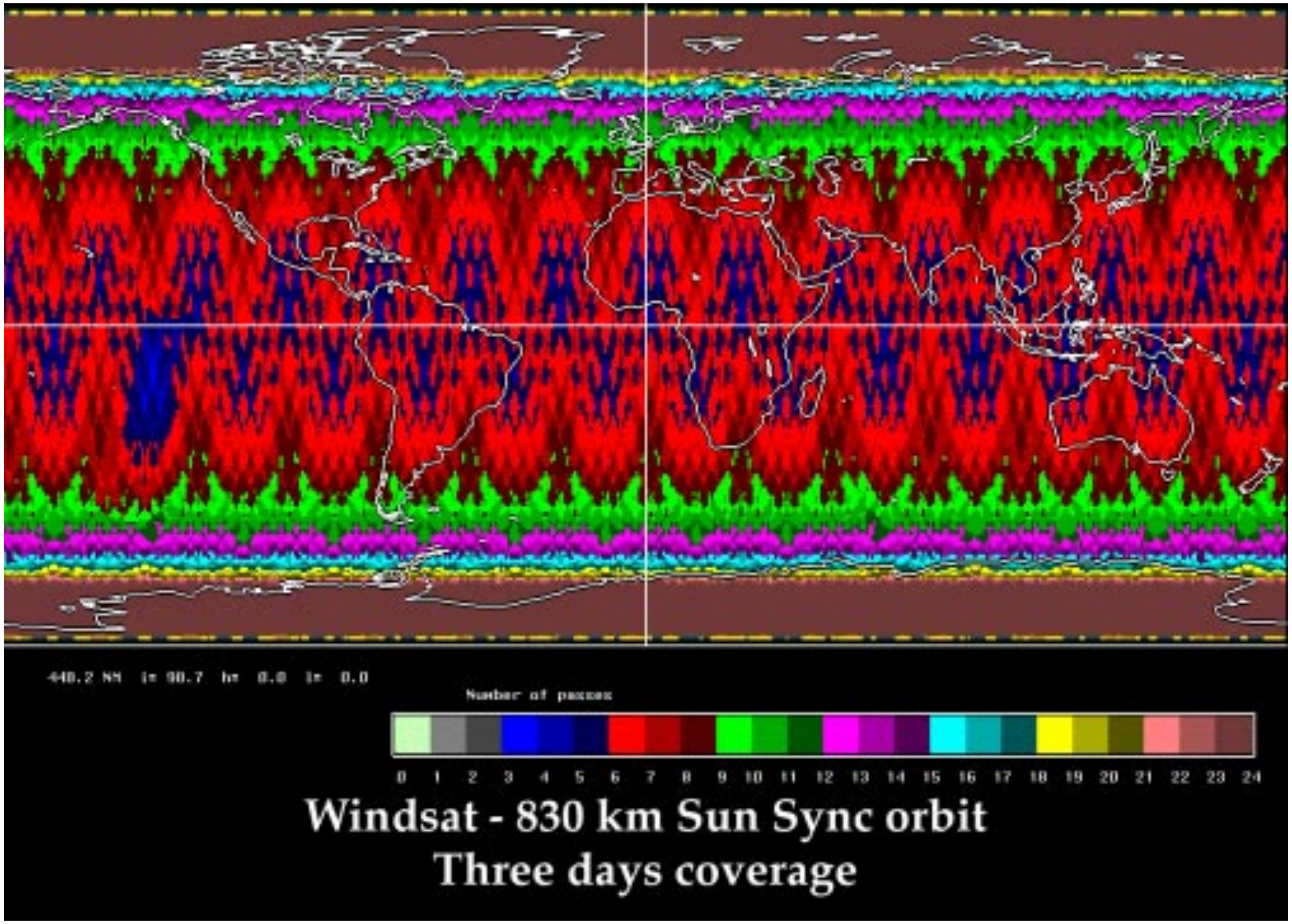
- **Insertion Error From Taurus Booster Is:**
  - **Inclination ±0.1°**
  - **Perigee ±24 Nm**
  - **Apogee ±10 Nm**
- **ΔV to Correct:**
  - **13.0 M/S for Inclination**
  - **84.9 M/S for Altitude**
  - **97.9 M/S Total**
- **Using Hydrazine Would Require ~ 37 Kg of Fuel to Correct Booster Errors**

Backup

Ground Covered in 1 Day - Sun Sync Orbit



Ground Covered in 3 Days - Sun Sync Orbit



Payload Conceptual Design and Requirements Review

T. Gutwein

System Allocations Summary Topics

- Conceptual Design Trades and Requirements Priorities
- System Allocation Process
- Summarize Mission Requirements to Payload
- Discuss Mission Sensitivity Analysis
- Subsystem Interfaces for Requirements Allocation Partitioning
- System Level Requirements to Subsystem Requirements Mapping/Impacts
- Subsystem Allocation Strings/Parameter Bias, Residual Bias, Random Error
  - \- Pointing - NEDT - Polarization - Beam Efficiency - Calibration
- Optimization Process
- Budgeting Process, Templates, and Summary Budgets
- Key System Level Analysis
  - \- Sensor Linearity - NEDT Sensitivity - Polarization Purity
- System Level Trades
  - Underhung Versus Overhung Sensor
  - Spin Rate and Pixel Integration
  - Deployable Antennas
  - Reflector Optics, Cryogenics, Solar Panel Profiles, Cold Reflector Packaging
- SRR Conceptual Design Pictorial

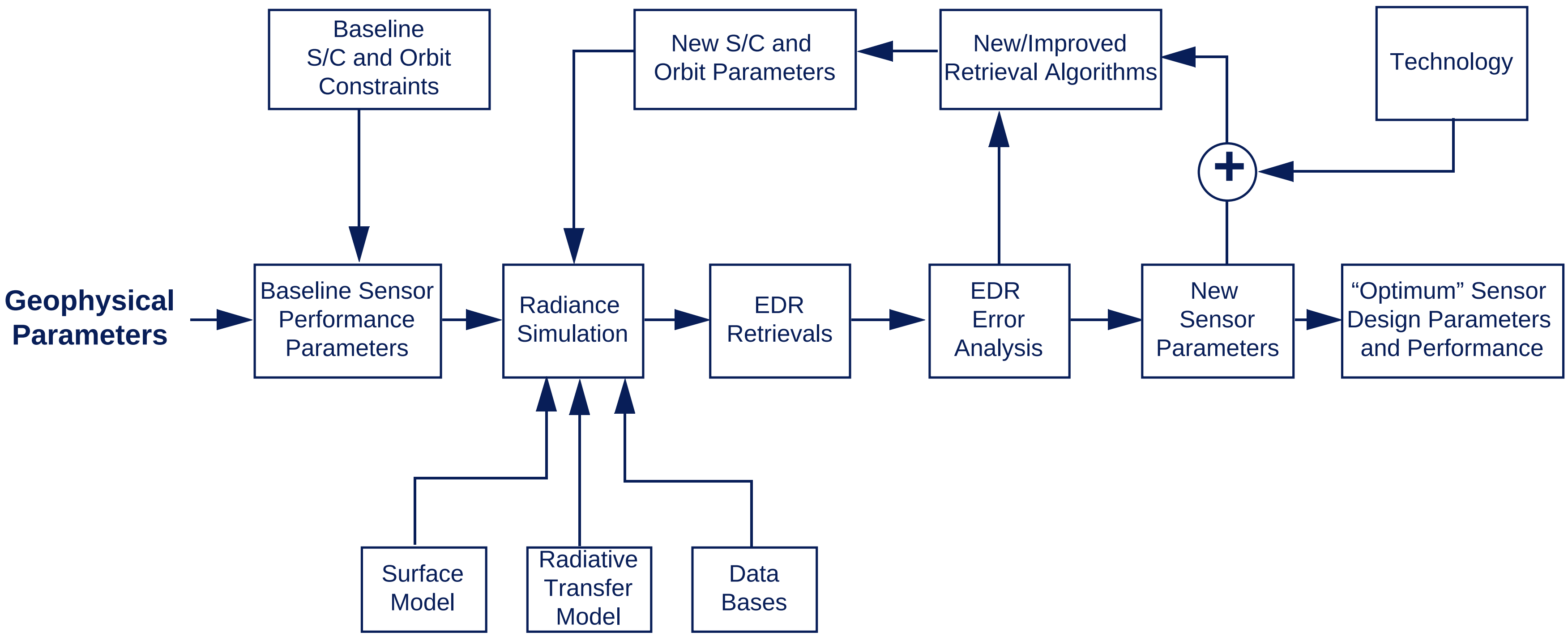
Major Conceptual Design Trades in Process

- Feed Architectural Alternatives
  - Stokes Vector Horns
  - Stokes Beam Forming
  - Optimization of Layout for Polarimetry
- Cold/Warm Load Concepts/Layouts/Packaging/Max Swath
- Spin Rate/Feed/Altitude/Sensor Size/Nyquist/Data Rate
- Polarization Purity Characterization and Validation
- NEDT Technology Requirements/Availability/Heritage
- Refinement of Bias and Random Partitioning
- Weight/Power/Off-the-Shelf/Custom/Minimization Studies

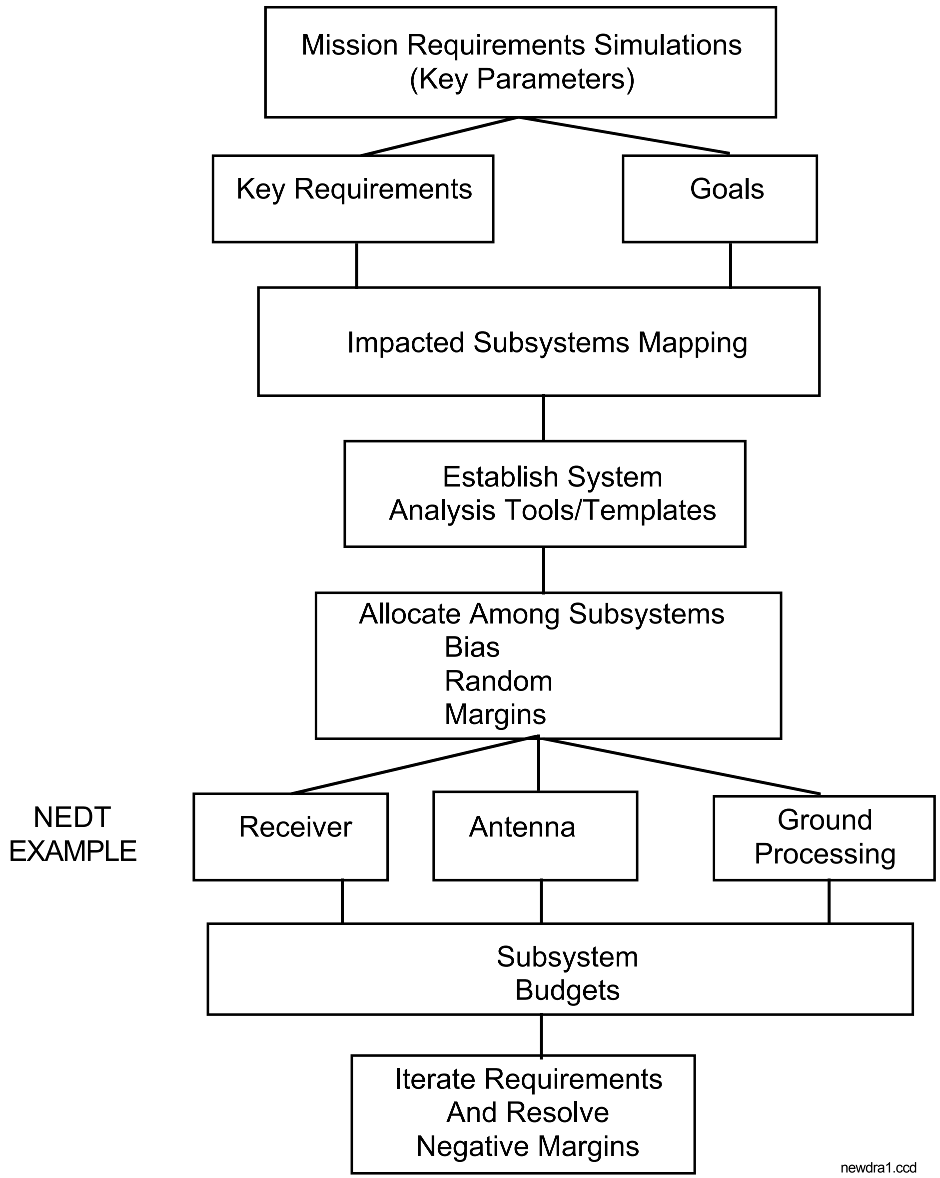
Critical Payload Requirements Priorities

- Polarization Purity and Range Validation
- NEDT
- Pointing
- Calibration Accuracy

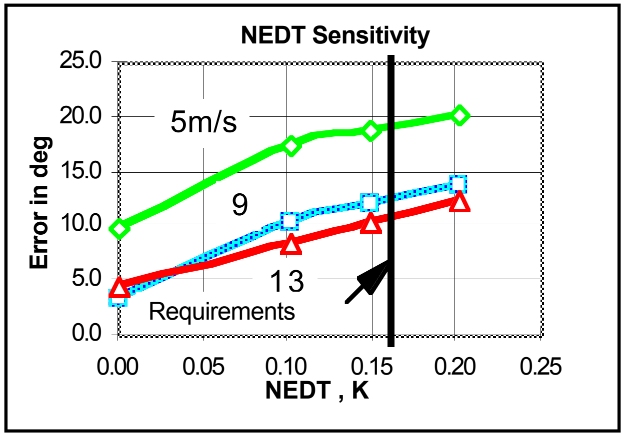
Allocation Process Optimizes Subsystem Payload Parameters for System Requirements



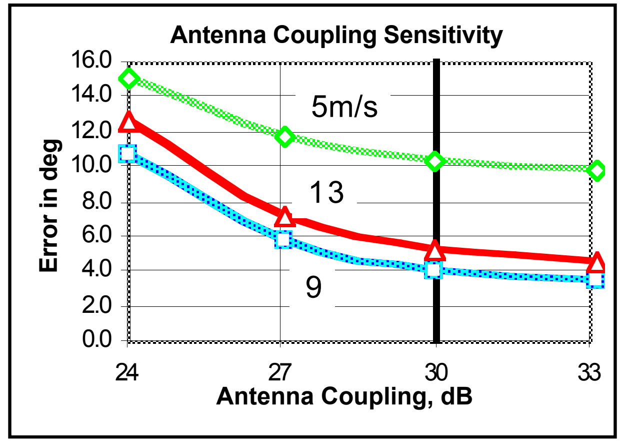
System Allocation Process



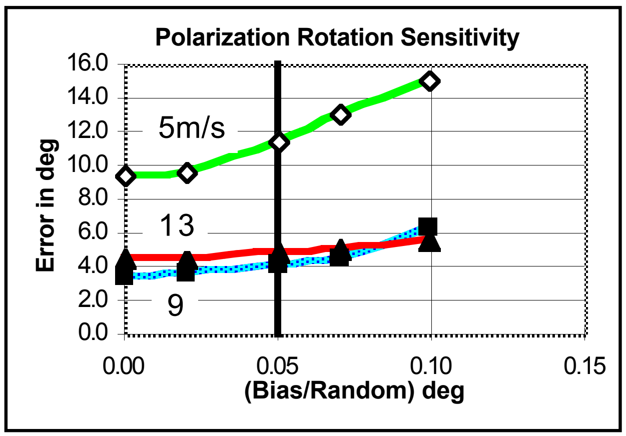
Flow Key Payload Requirements From Mission Sensitivity Analysis



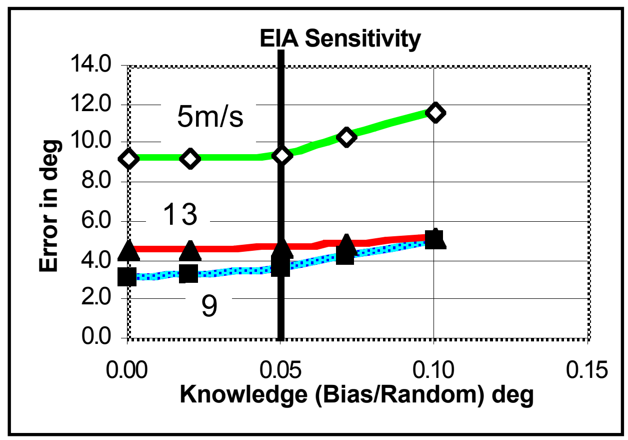
- NEDT Requirement
  0.1 to 0.2K



- Antenna Coupling/
  Crosstalk Requirement 30 dB

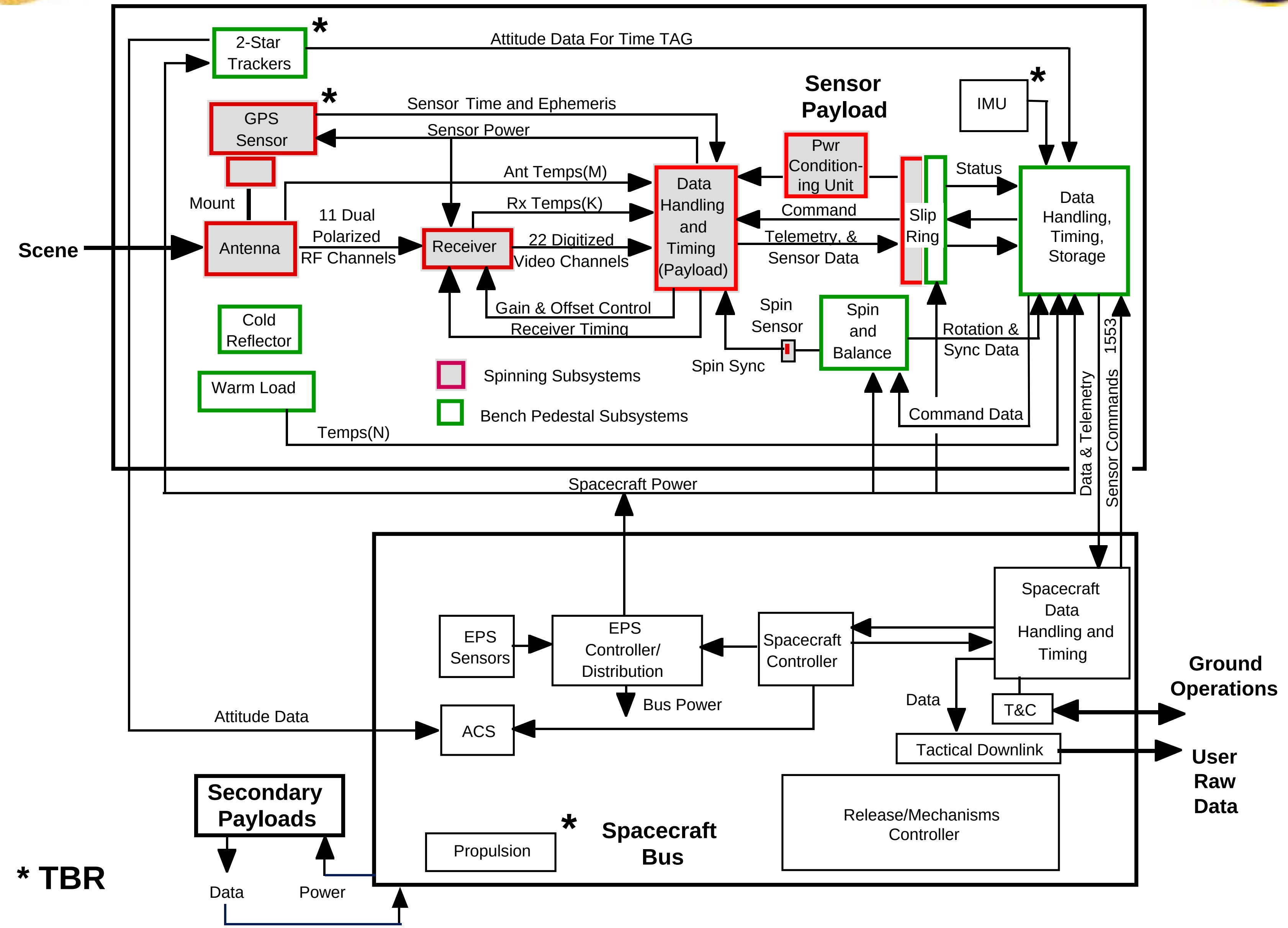


- Polarization Rotation
  Requirement 0.05 deg



- Earth Incidence Angle(EIA)
  Requirement 0.05 deg

Subsystem Interfaces



* TBR

Allocation Provides Trail to Subsystem Requirements and Compliance

- **Given Subsystem Functional Boundaries, Map Requirements to Subsystems**
- **Identify Subsystem Features and Performance Parameters As Impacting Above**
- **Allocate Each Subsystem a Subset of Requirements**
- **Designate the Major Subsystem Driver As the Master Budget Data Base**
- **Begin Process With Subsystem As Impacting System Level Requirement Which Includes Calibration and Ground Processing**
- **List Key Subsystem Drivers Against Each System Requirement**
- **Establish Bias, Calibration Bias Residual, and Random As Compliance Level Budgets Within Master Budget Subsystem**

Subsystems Impacted by Requirements

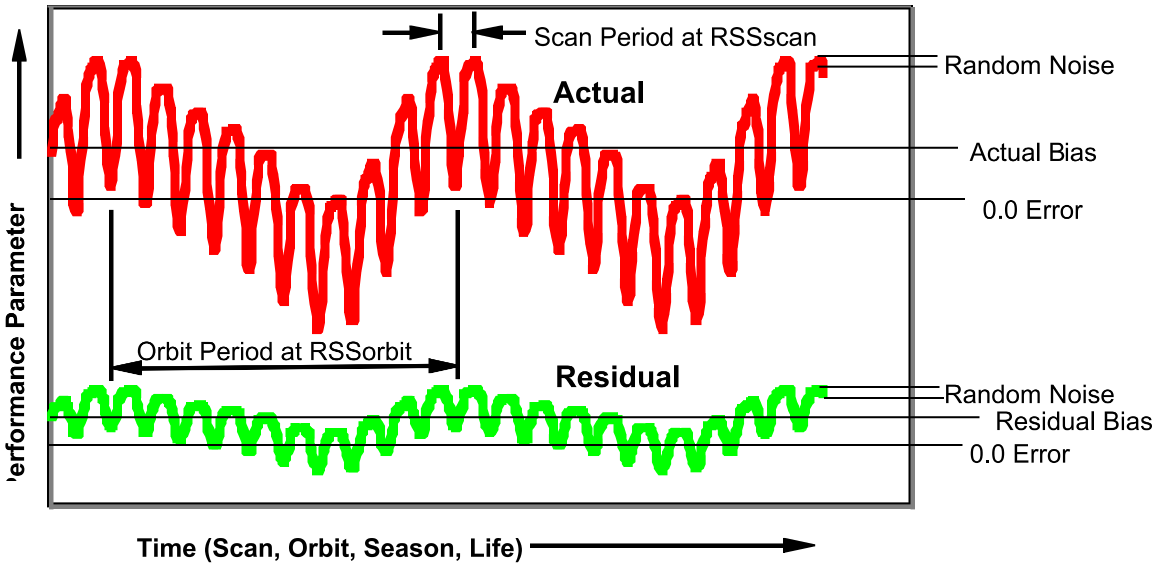
			Key System Requirements												System Goals			
			Pointing in deg[3]							Cal[4] Acc deg	Pol Pur dB	NEDTs[5] K	# Freq[4]	# Looks	Beam Eff %	Hor Res Km	Pixel Geo Km	Swath Width
			Control			Knowledge		Scan 45 deg	EIA deg									
			EIA[2]	PRA[2]	SAA[2]	EIA	PRA												
No	**Subsystems**		.25/1.0	1.0/1.0	0.15	.05/.05	.05/.05	0.80	50-56	.75/.25	30	0.1/0.2	2L/3P	2	95	20	4.0	Max
	Electrical	**Type[1]**																
1	Antenna	P,F,C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	Warm Load Cal	P,F,C			x					x	x		x	x				x
3	Cold Load Cal	P,F,C			x					x	x		x	x	x			x
4	Receiver	P,F,C			x						x	x	x				x	
5	Sensor Data Handling and Timing	P,F			x								x					
6	Slip Ring	P,F			x							x	x					
7	Spacecraft Controller	F																
8	Spacecraft Data Handling	F																
9	Bulk Storage	F											x	x			x	x
10	Data Time TAG	P,F			x								x					
11	Spacecraft Communications	F										x	x	x			x	x
12	Spacecraft EPS and Sensors	P,F,C										x						
13	Spacecraft T&C	F																
	Mechanical/Electrical																	
14	Spacecraft ACS	P,F,C																
15	Attitude Sensor(Star Tracker)	P,F,C				x	x											
16	IMU(3 axis)	P,F				x	x											
17	Ephemeris and Time(GPS)	P,F	x	x	x	x	x		x									
18	Reaction Control	P,F	x	x	x				x									
19	Spacecraft Mechanisms	P,F																
20	Spin and Balance	P,F,C	x	x	x	x	x											
21	Various																	
22	Thermal Control	P,F																
23	Payloads	P,F	x	x	x	x	x			x	x	x						
24	Spacecraft	F																
25	Structure	P,F,C	x	x	x	x	x	x	x									
26	Propulsion	F,C																
27	**Flight Software**	F																
28	**Ground**	P,F									x	x					x	x
29	**Calibration**	P,F	x	x	x	x	x	x	x	x	x	x			x	x	x	

Notes:
1. Type of Requirement: P=Performance, F=Functional, C=Constraint
2. EIA=Earth Angle of Incidence, PRA Is EIA Plane Rotation About Antenna Boresight, Clock is Spin Angle About Nadir
3. Pointing Paired Values are Random/Bias Requirements
4. Calibration, NEDT, and # Frequency Paired Values Are (I and Q) / (U and V)
5. Frequency Dependent

Key Derived Requirement Check List and Tracking

- Antenna Polarization Crosstalk Antenna Range Characterization Accuracy
- Antenna Poe Code Configuration Control and Validation For Stokes Crosstalk
- Antenna Beam Efficiency Orthogonal Polarization Difference Budget Is an Impact on Top of Antenna Crosspolarization Purity of 30 dB
- ACS Ephemeris (200 Meter) Versus Data Handling Timing (10 Microsecond) Requirement As Impacting GPS Component Requirement, Alternative Implementations, and Risk
- Scan Angle of 45 Deg+/-0.8 Deg Part of Equivalent EIA Control Budget
- Pixel Clock Resolution As Impacting Encoder and Data Timing Requirement
- Ground Station Data Rate Requirement Versus Sensor Size, Spin Rate, Feed Amplitude Taper, and Orbit Altitude
- Antenna RF to Mechanical Axis Alignments
  - ACS Allocated 0.015 Deg Bias Each for Az and El Values (Ant Coordinates)
  - Antenna Polarization Allocated 0.02 Deg for V/H or Polarization Rotation Impact Due to Range Characterization Error

WindSat Requirements Characterization and Budgeting Process



	Bias							
	Actuals			Residuals				
Items	1	2	3	4	5	6	7	8
Components	Scan	Orbit	Life	Scan	Orbit	Life	RSS	Random
Contributors	Values							
						Total RSS		
						Requirement		
						Margin		
						% Margin		

Note: 7=RSS of 1, 2, 3, 4, 5, and 6
Note: Bias and Random Contributors Partitioned/Tracked for Science

- **Random or Noise Term on Order of a Pixel Period and Unresolvable**
- **Systematic or Bias Components Related to Scan Period, Orbit Period, Season, and Life**
- **Actual Bias Reduced to a Residual Bias by Prediction/ Calibration/Ground Processing**
- **Performance Impacts Maintained As Separate Bias and Random Terms for Science**

NEDT Subsystems/Parameters As Impacted by Allocated Requirements

"String" System Diagram

KEY
Bias=1 Bias Residual=2 Random=3

- Calibration
- Thermal
  - Detector Lookup Channel Gain Balance(2)
  - Detector "k" Operating Point(2)
  - Scan Temp Channel Gain Stability Balance(3)
  - RPM(3)
  - Channel Gain Unbalance(3)
- Antenna
  - Horn Loss(3)
  - Waveguide Loss(3)
  - OMT Loss(3)
  - Isolation(1)
  - VSWR Mismatch(1)
- Receiver
  - Isolator Loss(3)
  - Filter Bandwidth(3)
  - Pre Filter Gain(3)
  - Rx NF(3)
  - Video Noise(3)
  - AGC(2)
  - A/D Quantization(2)
  - Integration Time(3)
  - A/D Dynamic Range(2)
  - Channel Crosstalk(1)
- EPS
  - Ground Loops(1)
  - Ripple Feed Through(3)
  - EMC(3)
- Slip Rings
  - BER Noise(3)
- S/C Communications
  - BER(3)
- Ground Systems
  - Pixel Integration Improvement(3)

NEDT PARAMETER SUBSYSTEM ALLOCATION STRING

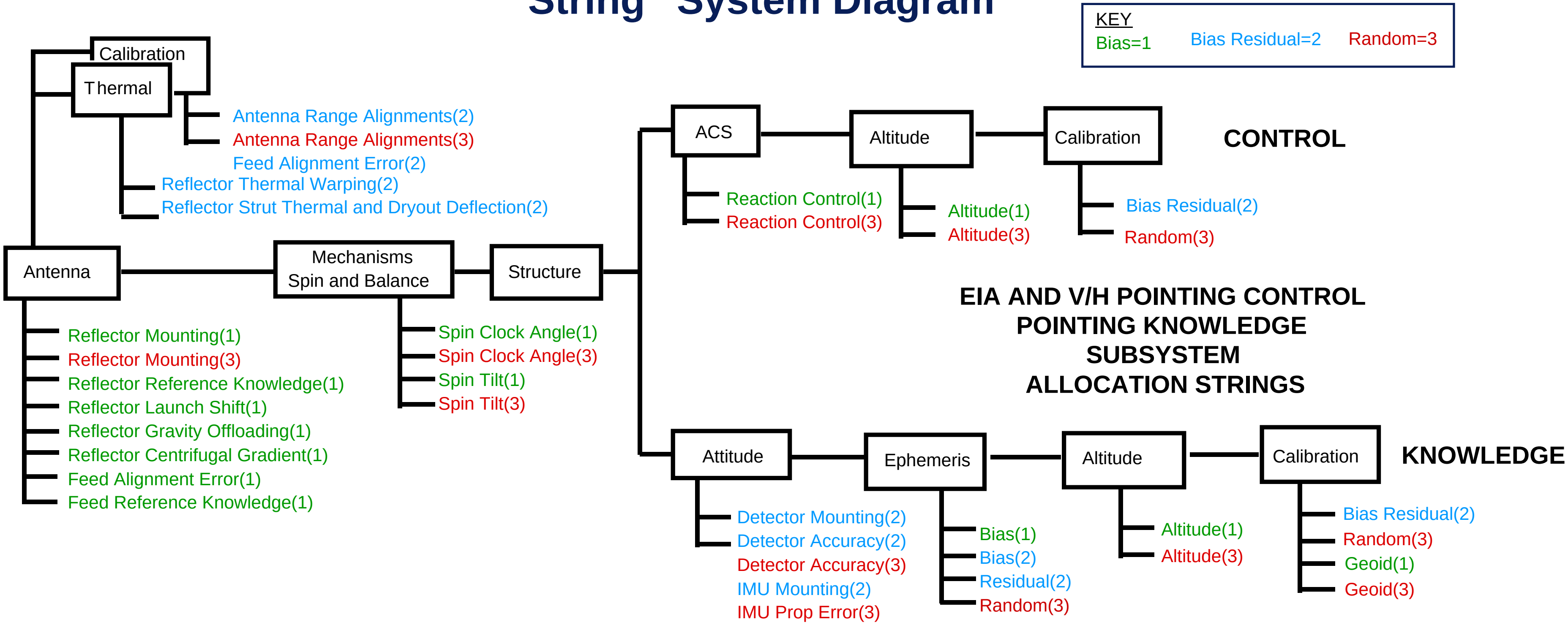
- **Master Budget Maintained By Receiver Subsystem**
- **Priority to Polarization Channels Highest to Lowest RF and 45 Deg Polarization**

Impacted Systems

Summary Allocated Subsystem Impacts	NEDT K 0.1/0.2
Antenna	x
Receiver	x
Slip Ring	x
Spacecraft Communications	x
Spacecraft EPS and Sensors	x
Payload Thermal Control	x
Ground	x
Calibration	x

EIA and PRA Pointing Subsystems/Parameters As Impacted by Allocated Requirements

“String” System Diagram



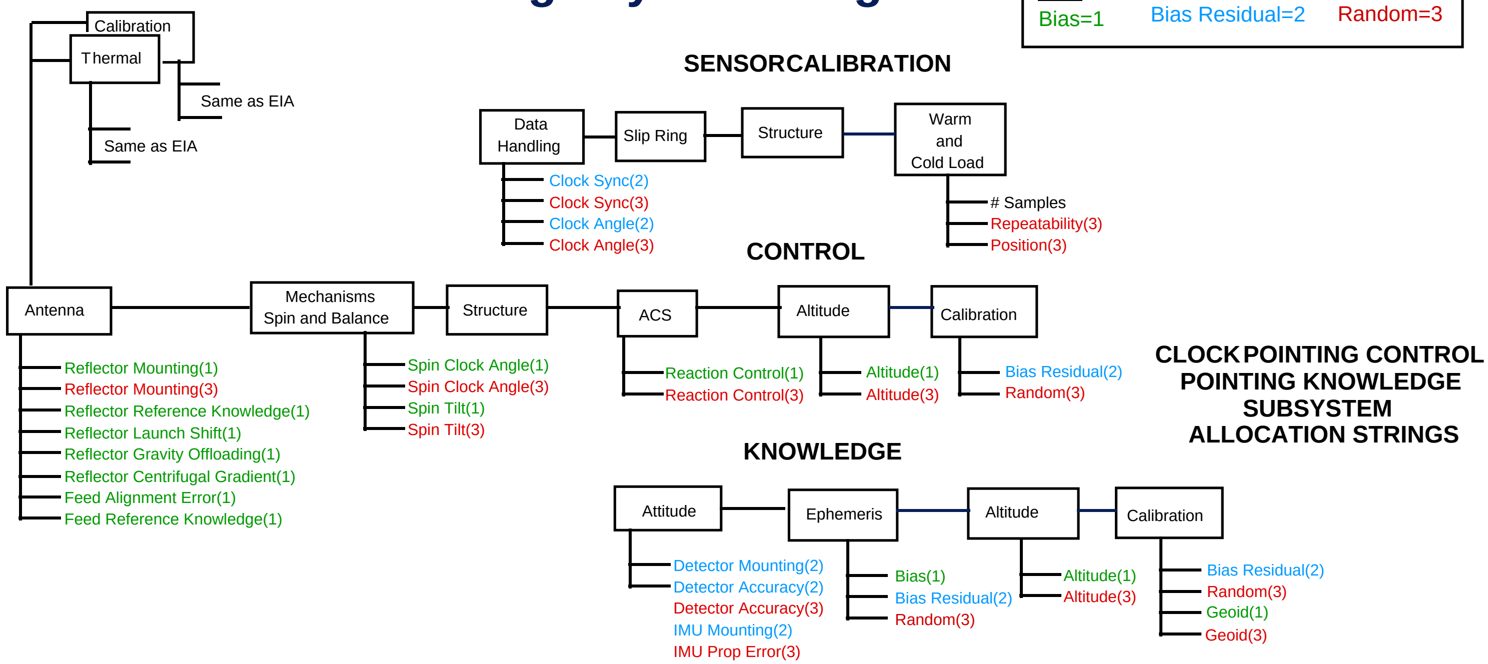
Impacted Subsystems

Summary Control Allocated Subsystem Impacts	EIA .25/1.0 PRA 1.0/1.0
Antenna	x
Ephemeris and Time(GPS)	x
Reaction Control	x
Mechanisms Spin and Balance	x
Payload Thermal Control	x
Structure	x
Calibration	x

Summary Knowledge Allocated Subsystem Impacts	EIA .05/.05 V/H .05/.05
Antenna	x
Attitude Sensor(Star Tracker)	x
IMU(3 axis)	x
Ephemeris and Time(GPS)	x
Mechanisms Spin and Balance	x
Payload Thermal Control	x
Structure	x
Calibration	x

SAA Pointing Subsystems/Parameters As Impacted by Allocated Requirements

“String” System Diagram



Impacted Subsystems

Summary Control Allocated Subsystem Impacts	SAA 0.15
Antenna	x
Warm Load Cal	x
Cold Load Cal	x
Receiver	x
Sensor Data Handling and Timing	x
Slip Ring	x
Data Time TAG	x
Ephemeris and Time(GPS)	x
Reaction Control	x
Mechanisms Spin and Balance	x
Payload Thermal Control	x
Structure	x
Calibration	x

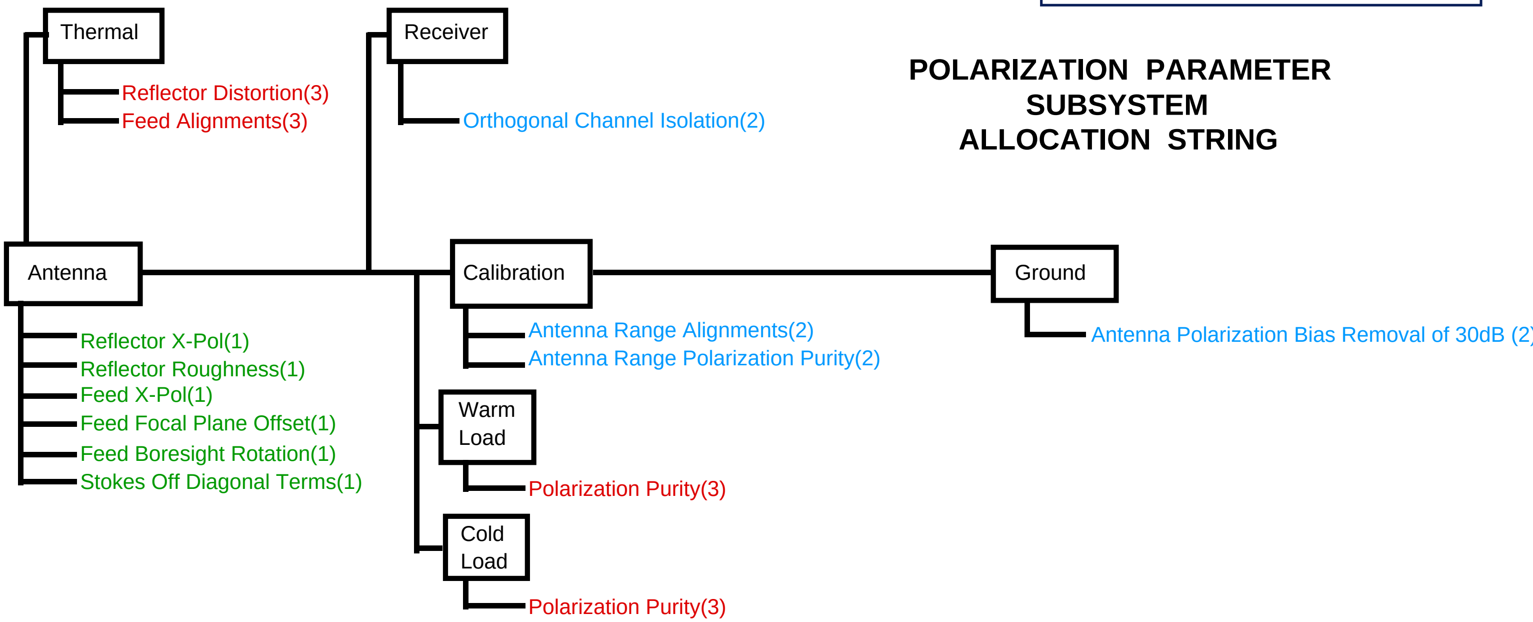
Summary Knowledge Allocated Subsystem Impacts	SAA 0.05
Antenna	x
Warm Load Cal	x
Cold Load Cal	x
Receiver	x
Sensor Data Handling and Timing	x
Slip Ring	x
Data Time TAG	x
Attitude Sensor(Star Tracker)	x
IMU(3 axis)	x
Ephemeris and Time(GPS)	x
Spin and Balance	x
Payloads	x
Structure	x
Calibration	x

Polarization Purity Subsystems/Parameters As Impacted by Allocated Requirements

"String" System Diagram

KEY
Bias=1 Bias Residual=2 Random=3

POLARIZATION PARAMETER SUBSYSTEM ALLOCATION STRING



Impacted Systems

Summary Polarization Allocated Subsystem Impacts	Pol Pur dB
	30
Antenna	x
Warm Load Cal	x
Cold Load Cal	x
Receiver	x
Payload Thermal Control	x
Ground	x
Calibration	x

Beam Efficiency Subsystems/Parameters As Impacted by Allocated Requirements

"String" System Diagram

KEY
Bias=1 Bias Residual=2 Random=3

Antenna — 95% — Calibration

Antenna:
- Reflector Roughness(1)
- Feed Phase(1)
- Spillover(1)
- Spillover(3)
- Cross polarization(1)
- Feed Focal Plane Offset(1)
- Beam Efficiency Asymmetry(2)

Calibration:
- Residual Bias(2)

BEAM EFFICIENCY PARAMETER SUBSYSTEM ALLOCATION STRING

Cold Load — As Required% for Cal — Calibration

Cold Load:
- Reflector Roughness(1)
- Feed Phase(1)
- Spillover(1)
- Spillover(3)
- Cross polarization(1)
- Feed Focal Plane Offset(1)
- Number of Samples(1)

Calibration:
- Residual Bias(2)
- Sample Uniformity(3)

Impacted Systems

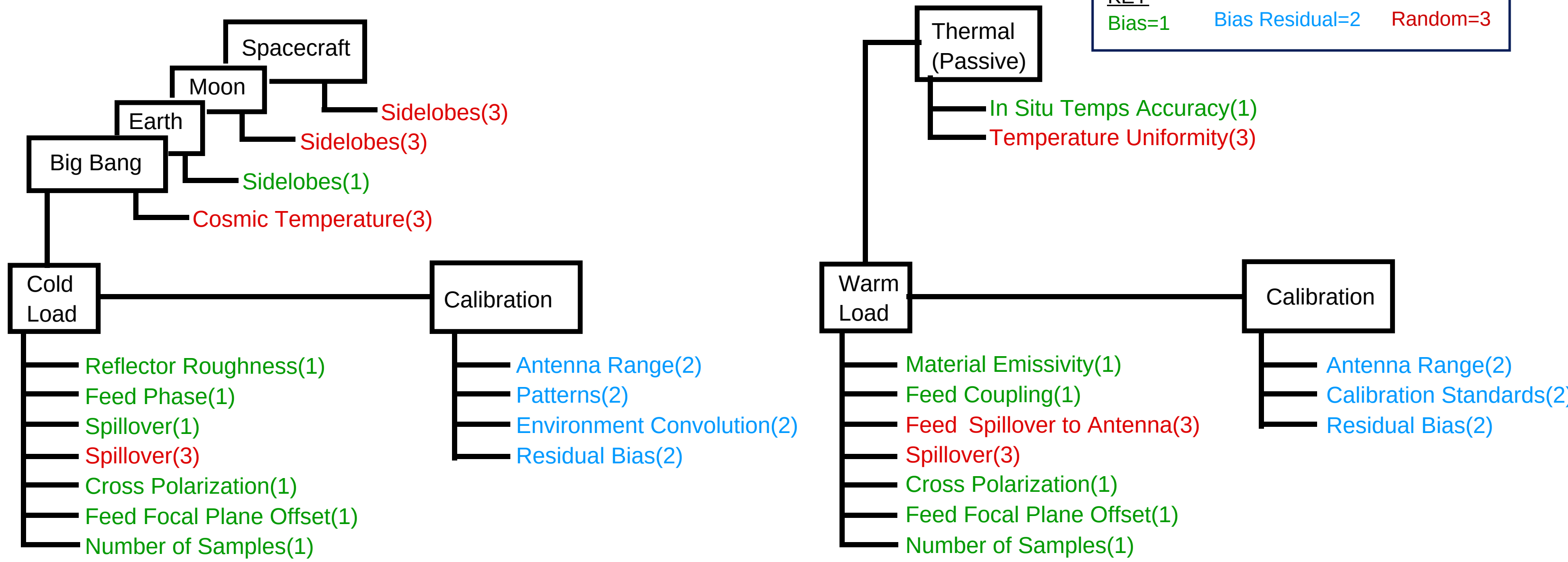
Summary Beam Efficiency Allocated Subsystem Impacts	Beam Eff %
	95
Antenna	x
Cold Load Cal	x
Calibration	x

Note:
Tracking Beam Efficiency Asymmetry as a Derived Science Requirement

Calibration Subsystems/Parameters As Impacted by Allocated Requirements

"String" System Diagram

KEY
Bias=1 Bias Residual=2 Random=3



CALIBRATION PARAMETER SUBSYSTEM ALLOCATION STRING

Impacted Systems

Summary Calibration Allocated Subsystem Impacts	Cal Acc deg .75/.25
Antenna	x
Warm Load Cal	x
Cold Load Cal	x
Payload Thermal Control	x
Calibration	x

Subsystems Impacted by Requirements

			Key System Requirements												System Goals			
			Pointing in deg[3]							Cal[4]	Pol		#	#	Beam	Hor	Pixel	Swath
			Control			Knowledge		Scan	EIA	Acc	Pur	NEDTs[5]	Freq[4]	Looks	Eff	Res	Geo	Width
			EIA[2]	PRA[2]	SAA[2]	EIA	PRA	45 deg	deg	deg	dB	K			%	Km	Km	
No	**Subsystems**		.25/1.0	1.0/1.0	0.15	.05/.05	.05/.05	0.80	50-56	.75/.25	30	0.1/0.2	2L/3P	2	95	20	4.0	Max
	Electrical	**Type[1]**																
1	Antenna	P,F,C	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	Warm Load Cal	P,F,C			x					x	x		x	x				x
3	Cold Load Cal	P,F,C			x					x	x		x	x	x			x
4	Receiver	P,F,C			x						x	x	x				x	
5	Sensor Data Handling and Timing	P,F			x								x					
6	Slip Ring	P,F			x							x	x					
7	Spacecraft Controller	F																
8	Spacecraft Data Handling	F																
9	Bulk Storage	F											x	x			x	x
10	Data Time TAG	P,F			x								x					
11	Spacecraft Communications	F										x	x	x			x	x
12	Spacecraft EPS and Sensors	P,F,C										x						
13	Spacecraft T&C	F																
	Mechanical/Electrical																	
14	Spacecraft ACS	P,F,C																
15	Attitude Sensor(Star Tracker)	P,F,C				x	x											
16	IMU(3 axis)	P,F				x	x											
17	Ephemeris and Time(GPS)	P,F	x	x	x	x	x		x									
18	Reaction Control	P,F	x	x	x				x									
19	Spacecraft Mechanisms	P,F																
20	Spin and Balance	P,F,C	x	x	x	x	x											
21	Various																	
22	Thermal Control	P,F																
23	Payloads	P,F	x	x	x	x	x			x	x	x						
24	Spacecraft	F																
25	Structure	P,F,C	x	x	x	x	x	x	x									
26	Propulsion	F,C																
27	**Flight Software**	F																
28	**Ground**	P,F									x	x					x	x
29	**Calibration**	P,F	x	x	x	x	x	x	x	x	x	x			x	x	x	

Notes:

1. Type of Requirement: P=Performance, F=Functional, C=Constraint
2. EIA=Earth Angle of Incidence, PRA Is EIA Plane Rotation About Antenna Boresight, Clock is Spin Angle About Nadir
3. Pointing Paired Values are Random/Bias Requirements
4. Calibration, NEDT, and # Frequency Paired Values Are (I and Q) / (U and V)
5. Frequency Dependent

Subsystem's Master Budget Listing Trail and Process

- Pointing Control Maintained by ACS (Mike Mook)
- NEDT Maintained by Receiver (Joe Xavier)
- Scan Angle Error Maintained by ACS (Mike Mook)
- Data Handling Synchronization and Resolution Error Maintained by Sensor Data Handling Subsystem (Stu Nicholson)
- Warm Load Calibration Maintained (Peter Gaiser)
- Cold Load Calibration Maintained (Peter Gaiser)
- Polarization Purity Maintained by Antenna (Wendy Lippincott)
- Beam Efficiency Maintained by Antenna (Wendy Lippincott)
- Power and Weight Budget Maintained by Structures (Stefan Cottle)
- All Budgets at or Near Zero or Negative Margins Are Being Worked

Subsystem Summary Level Budgets

03. NEDT Summary Allocations	Impacted Subsystems							
	Random			Ground				
	Ant	Rx	Total RSS	Int Beams	EFOV	Requirement	Margin	%Margin
03.01. 37 GHz	0.040	0.400	0.402	20	0.090	0.100	0.010	10
03.02. 23.8 GHz	0.030	0.568	0.569	10	0.180	0.200	0.020	10
03.03. 18.7 GHz	0.030	0.425	0.426	10	0.135	0.150	0.015	10
03.04. 10.7 GHz	0.030	0.425	0.426	10	0.135	0.150	0.015	10
03.05. 6.8 GHz	0.030	0.568	0.569	10	0.180	0.200	0.020	10

Basis of Allocation is a Scene Temperature of 250 K
BER of Data Handling, Slip Rings, and Communications Subsystems is Insignificant

Allocated Subsystem Losses in dB as Impacting NEDT:

Subsystem	6.8	10.7	18.7	23.8	37
Antenna					
Antenna Pre LNA Loss	0.30	0.30	0.30	0.30	0.40
Receiver					
Receiver Pre LNA Losses	0.30	0.15	0.18	0.18	0.18
Total(dB)	0.60	0.45	0.48	0.48	0.58

- **NEDT Maintained by Receiver (Joe Xavier)**
- **Basis of NEDT Allocation Is T=250K**
- **Sensor Dynamic Range Requirement Is Maintained Between 3K to 330K**

Subsystem Summary Level Budgets

01. Pointing Budget Summary Totals	**Bias**				**Random**			
	Bias	Required	Margin	% Margin	Random	Required	Margin	% Margin
01.04. Incidence Angle Control(EIA)	0.443	1.000	0.557	56	0.041	0.250	0.209	84
01.05. Incidence Angle Knowledge(EIA)	0.039	0.050	0.011	22	0.020	0.050	0.030	60
01.06. PRA Rotation Control	0.143	1.000	0.857	86	0.034	1.000	0.966	97
01.07. PRA Rotation Knowledge	0.032	0.050	0.018	36	0.019	0.050	0.031	62
01.08. SAA Spin Rotation Control	0.076	0.150	0.074	49	0.034	0.050	0.016	32

EIA=Earth Incidence Angle PRA=Polarization Rotation Angle SAA=Sensor Azimuth Angle

Allocated a Data Handling Synchronization SAA of 0.002 deg As an Insignificant Percentage Of Total 0.15 deg Pointing Requirement
Basis of Estimate is a 10 microsecond Resolution Out Of A 2 Second Spin Period

Allocation Of Pointing Budgets To Subsystems:

	Impacted Subsystems							
Bias	Antenna	Ephemeris	ACS	Orbit Error (RCS)	Geoid	Antenna/ Bench	Spin	Data Handling
01.04. Incidence Angle Control(EIA)	0.020	0.000	0.200	0.400	0.000	0.010		
01.05. Incidence Angle Knowledge(EIA)	0.020	0.003	0.030	0.000	0.001	0.010		
01.06. PRA Rotation Control	0.020	0.000	0.150	0.000	0.000	0.010		
01.07. PRA Rotation Knowledge	0.020	0.002	0.020	0.000	0.000	0.010		
01.08. SAA Spin Rotation Control	0.020	0.000	0.070	0.000	0.000	0.020	0.080	0.000

Allocation Of Pointing Budgets To Subsystems:

	Impacted Subsystems							
Random	Antenna	Ephemeris	ACS	Orbit Error (RCS)	Geoid	Antenna/ Bench	Spin	Data Handling
01.04. Incidence Angle Control(EIA)	0.015	0.000	0.040	0.000	0.000	0.003		
01.05. Incidence Angle Knowledge(EIA)	0.015	0.003	0.015	0.000	0.001	0.003		
01.06. PRA Rotation Control	0.015	0.000	0.030	0.000	0.000	0.002		
01.07. PRA Rotation Knowledge	0.015	0.002	0.010	0.000	0.000	0.002		
01.08. SAA Spin Rotation Control	0.010	0.000	0.030	0.000	0.000	0.000	0.005	0.002

- **Pointing Control Maintained by ACS (Mike Mook)**
- **Scan Angle Error Maintained by ACS (Mike Mook)**
- **Data Handling Synchronization and Resolution Error Maintained by Sensor Data Handling Subsystem (Stu Nicholson)**

Subsystem Summary Level Budgets

02. Antenna Polarization Purity in dB Summary Tools

- Range Requirement for -30 dB Residual With Multipath Gating = -59 dB
- Positive Margin Exists With Prospective Ranges by Achieving -60 to -70 dB
- Details Presented Within Antenna Subsystem Derived Range Requirements and Analysis

- Polarization Purity Maintained by Antenna (Wendy Lippincott)
- Low Budget Margins Will Be Handled by Revised Requirements Among Subsystems or Relaxation of System Level Requirements

Subsystem Summary Level Budgets

04.01 37 GHz Beam Efficiency

Contributor	37 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		96.21	96.21
Feed Phase	1	deg rms		99.88	99.88
Spillover	24	dB taper	99.50	99.50	99.00
Crosspolarization	26	dB		99.75	99.75
				Total	94.90
				Goal	95.00

04.02 18.7 GHz Beam Efficiency

Contributor	18.7 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		99.02	99.02
Feed Phase	1	deg rms		99.97	99.97
Spillover	24	dB taper	99.50	99.50	99.00
Crosspolarization	26	dB		99.75	99.75
				Total	97.75
				Goal	95.00

04.03 10.7 GHz Beam Efficiency

Contributor	10.7 GHz				
	Parameter		Efficiency Impacts		
	Value	Units	Random	Bias	Total
Reflector Roughness	5	mils rms		99.68	99.68
Feed Phase	1	deg rms		99.99	99.99
Spillover	24	dB taper	99.50	99.50	99.00
Crosspolarization	26	dB		99.75	99.75
				Total	98.42
				Goal	95.00

- **Beam Efficiency Maintained by Antenna (Wendy Lippincott)**

Subsystem Summary Level Budgets

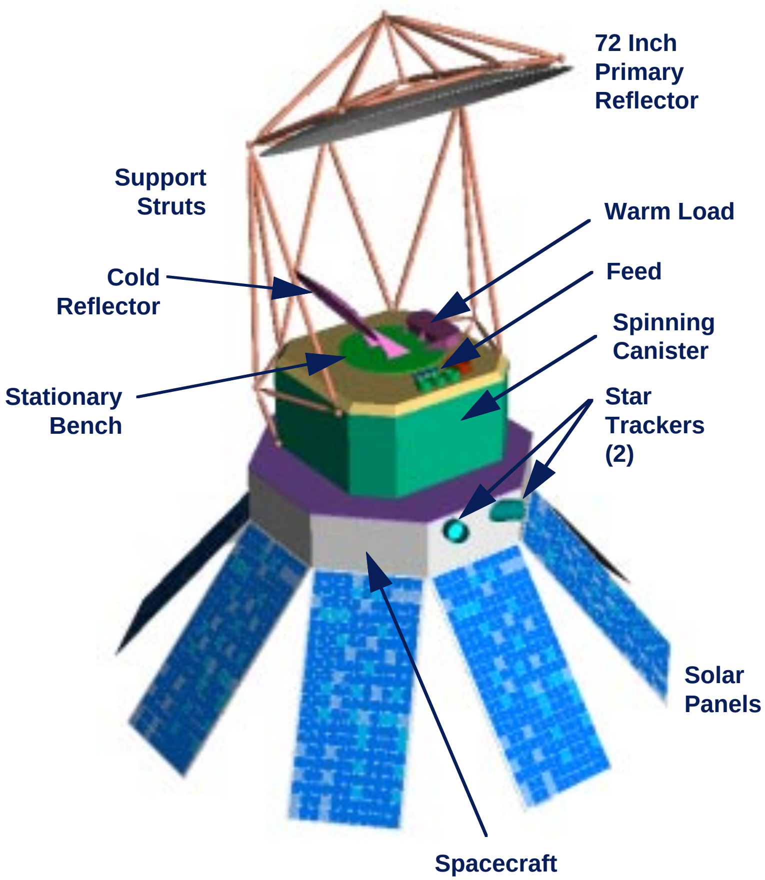
05. Absolute Accuracy

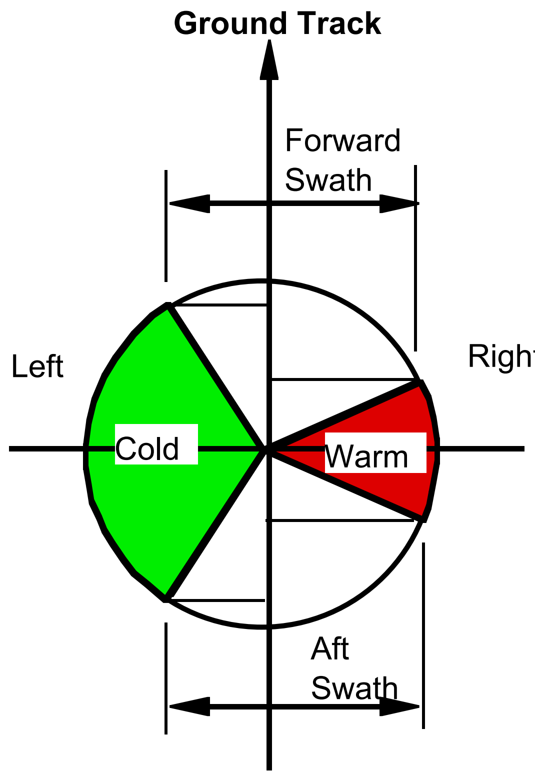
Impacted Subsystems	Stokes Parameter	
Contributor	**I/Q**	**U/V**
Warm Load	- 0.15+/-0.15	+/- 0.10
Cold Load	+ 0.4+/-0.15	+/- 0.15
Rx Nonlinearities	-0.5 +/-0.10	+/- 0.10
Antenna Beam Efficiency	+/- 0.15	+/- 0.15
Receiver Gain Drift	+/- 0.06	+/- 0.06
Totals	0.69	0.21
Requirement	**0.75**	**0.25**
Margin	**0.06**	**0.04**

- **Warm Load Calibration Maintained by Peter Gaiser**
- **Polarization Purity Requirement of Warm Load Greater Than 40 dB=0.03 K for 300 K**
- **Polarimetric Channel Requirements Are Aggressive**

Subsystem Summary Level Budgets

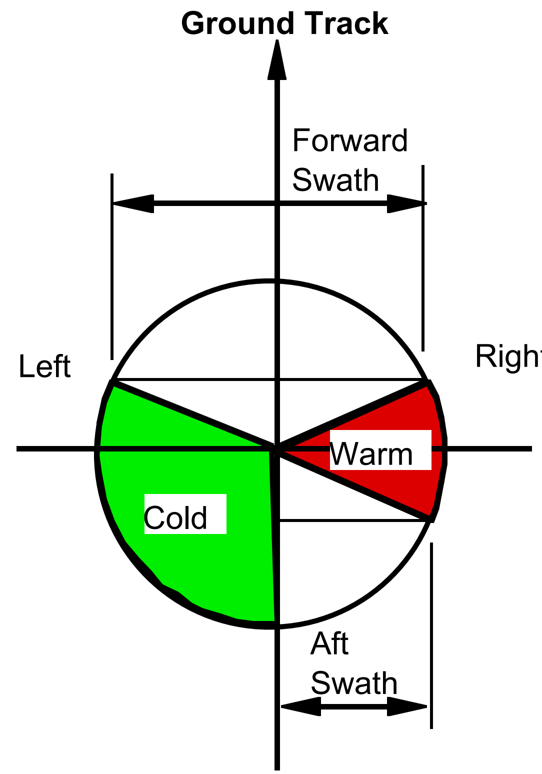
- **Example Subsystem Swath Allocation Among Reflector, Warm, and Cold Load**





Symmetyrical Cal Case

- **Forward Swath 913 Km**
- **Aft Swath 913 Km**

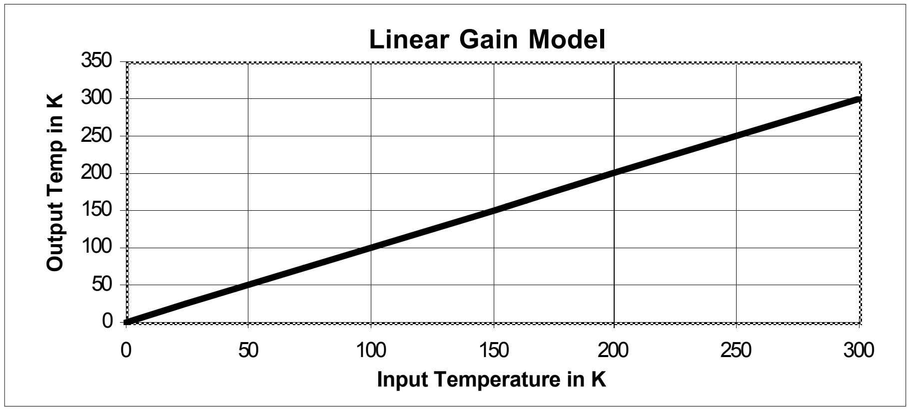


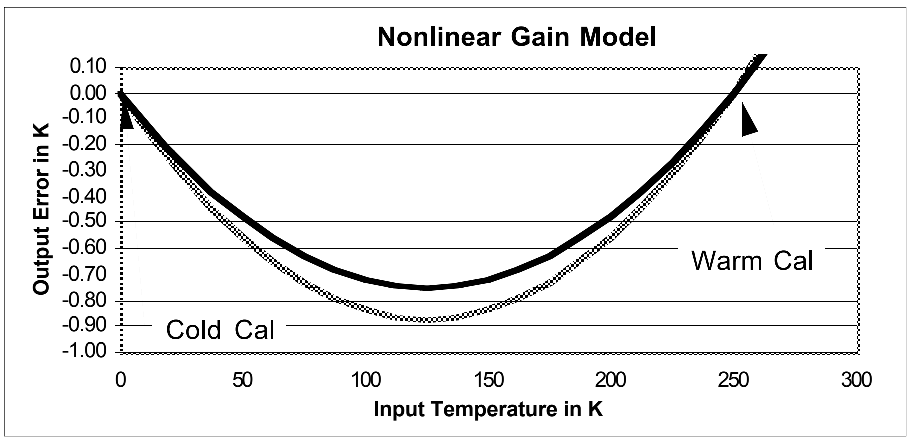
Assymetrical Cal case

- **Forward Swath 1053 Km**
- **Aft Swath 769 Km**

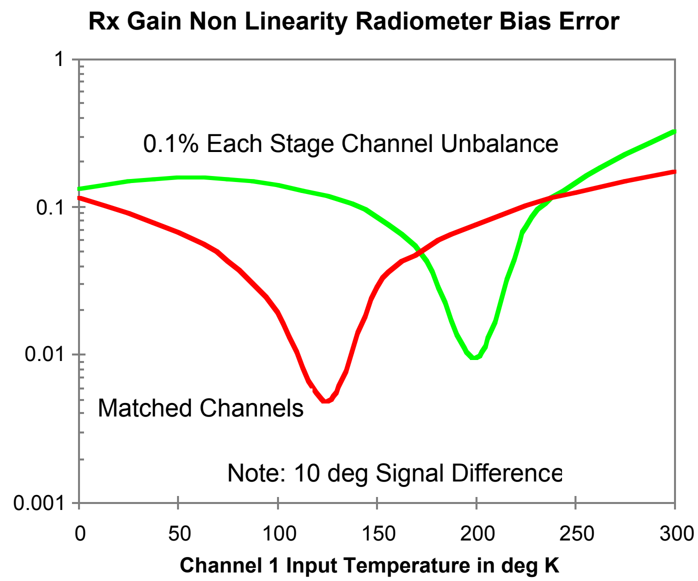
Key System Level Analysis

- **Payload Polarimeter Channel Linearity Is a Critical Parameter Requiring Matched Channels**





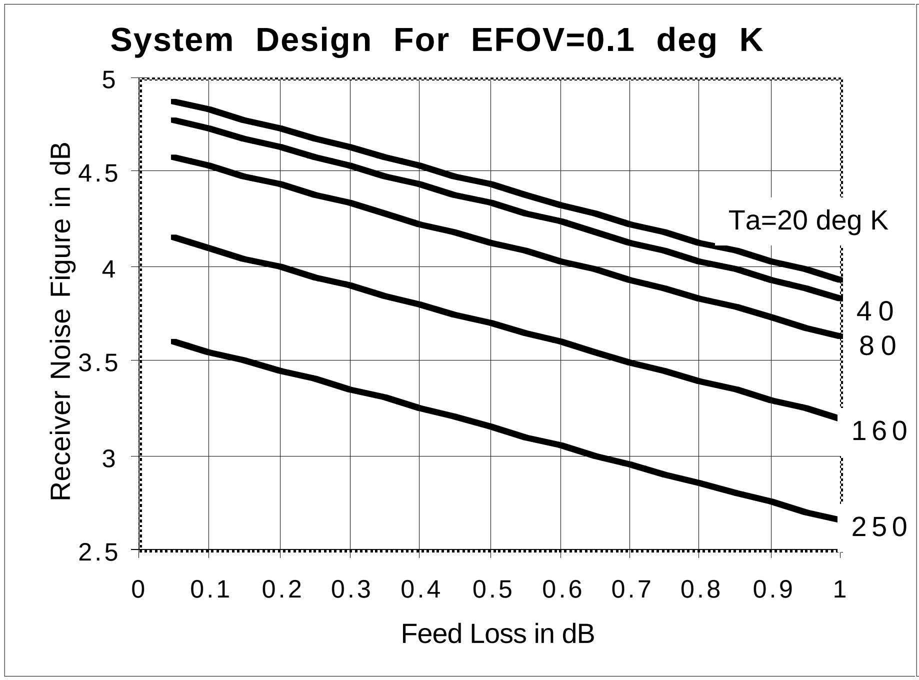
Receiver Linearity State Matrix	Values Channel1	Values Channel2	Units
RF: Linearity	0.6	0.7	+/-%
Detector: Linearity	0.6	0.7	%
Video: Linearity	0.6	0.7	%
A/D: Linearity	0.6	0.7	%
RSS of Linearities	1.200	1.400	%
Equivalent dB's	0.052	0.060	dB
Max K Deviation From Linear	0.750	0.875	K

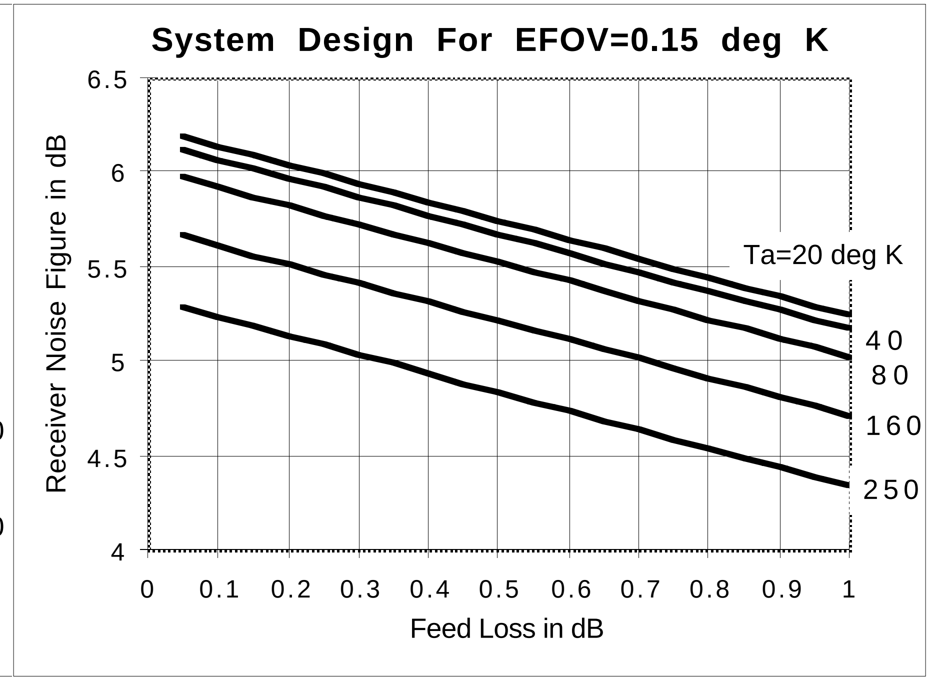


- **Allocated Requirements for Matched Channels Is on the Order of 0.1%**
- **Residual Bias Term Common Mode Assumption for Third and Fourth Stokes Parameter**

Key System Level Analysis

- **Allocated System Design Sensitivity to NEDT for 20 Beams Integrated at 37 GHz**



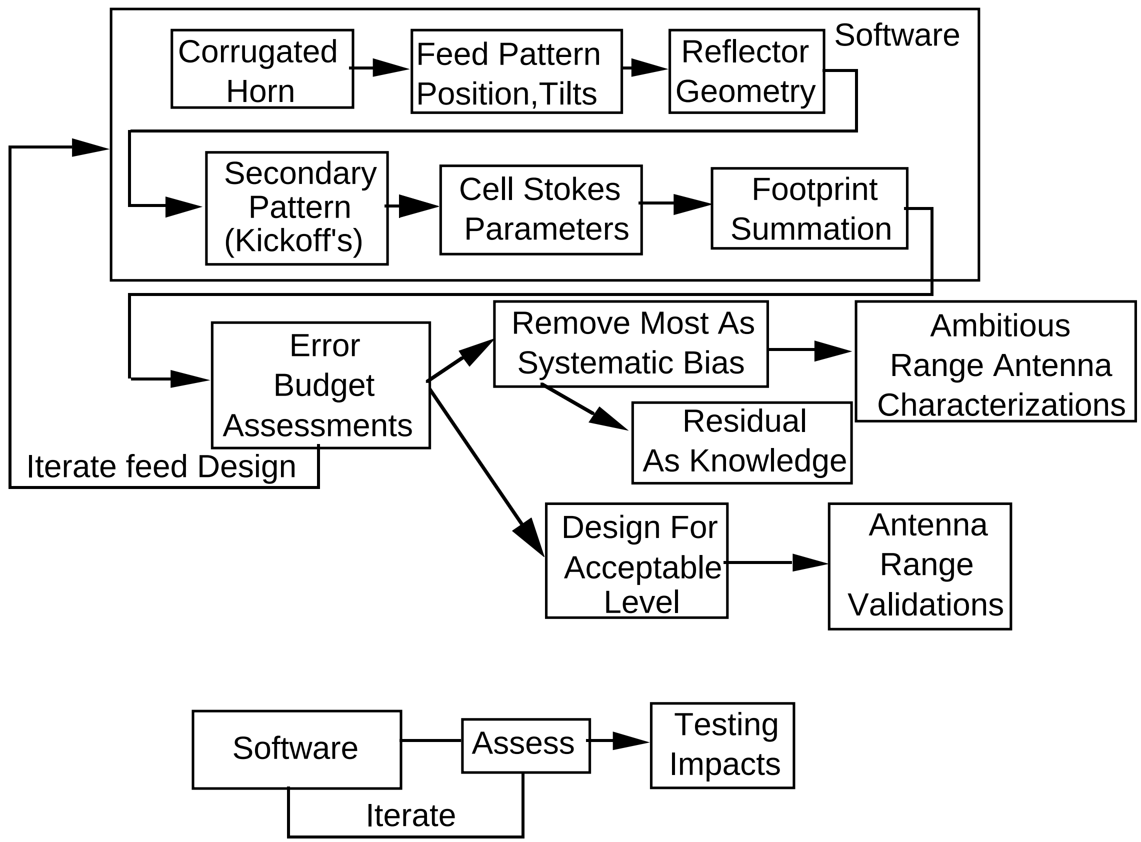


- **Feasible Antenna and Receiver Subsystem Parameters for Required NEDT Performance**
- **20 Beams Integrated at 37 GHz**

Key System Level Analysis

- **Polarization Purity Requirement**

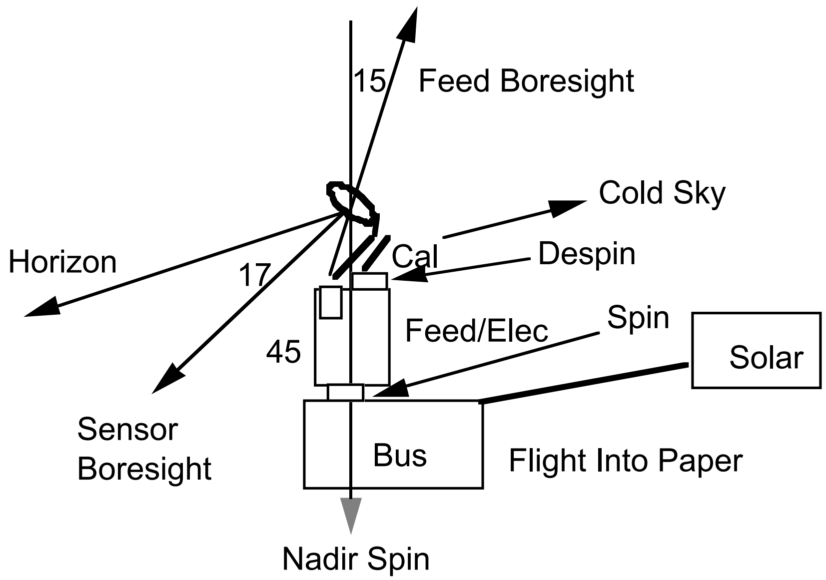
Analysis and Test Process



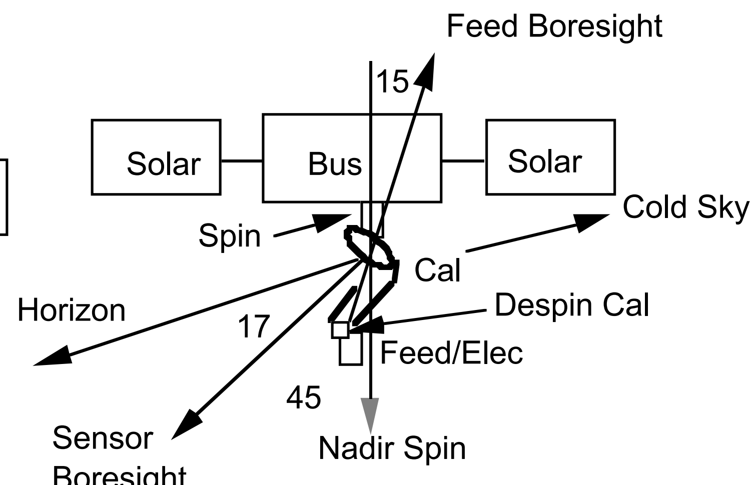
- **Range Calibration of Crosstalk Terms Reduces Impact to an Effective 30 dB Level**

System Level Trade Studies

- **Underhung Versus Overhung Payload**



Overhung



Underhung

Pros

- **External Cal Cold Sky Unobstructed**
- **SSMI Heritage for Radiometer Design**
- **Feed Spillover Views Cold Sky**

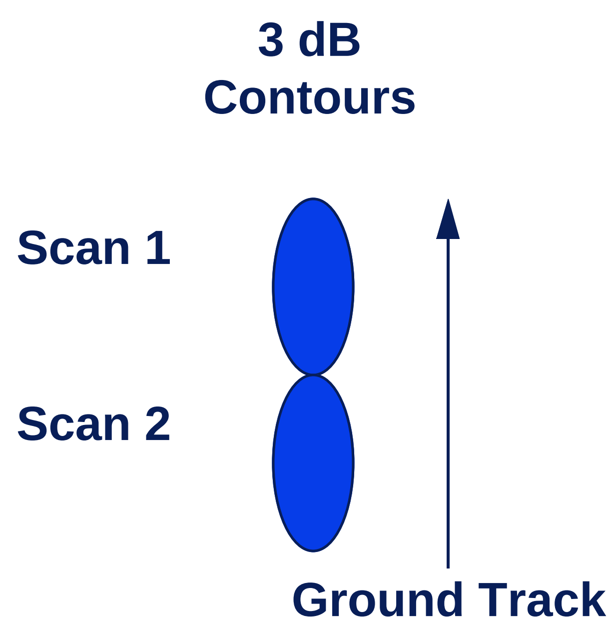
Pros

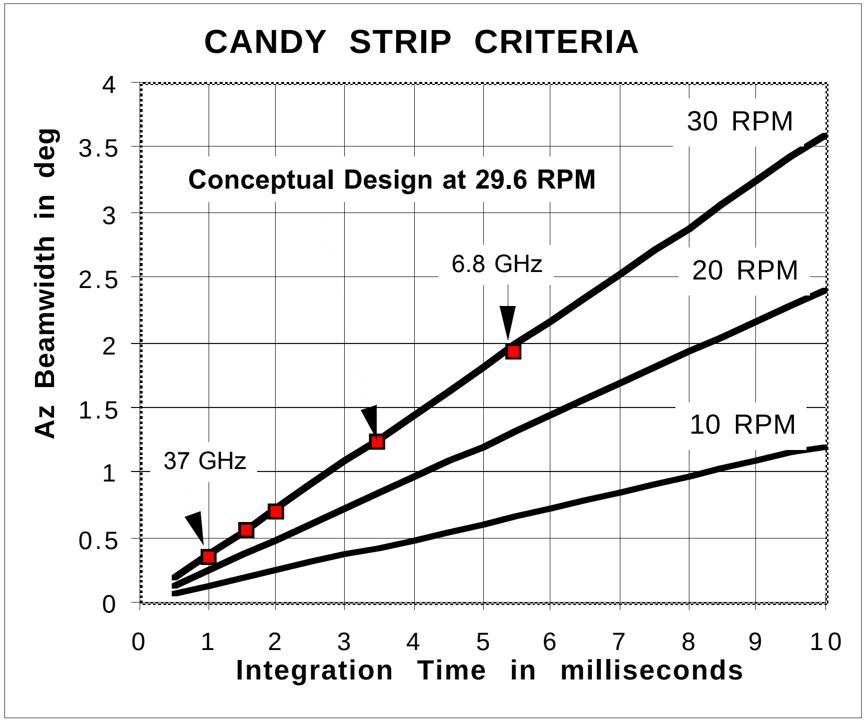
- **Low Bus Swath Blockage**

System Level Trade Studies

- Spin Rate Trail for Conceptual Design Concluded With Optimum Beam Efficiency, Reduced Data Rate, Minimum Feed Complexity, and Packaging Without Orbital Deployments Mechanisms
- 2 Samples Per 3 dB Beamwidth
- Required Nyquist Sampling Along Track

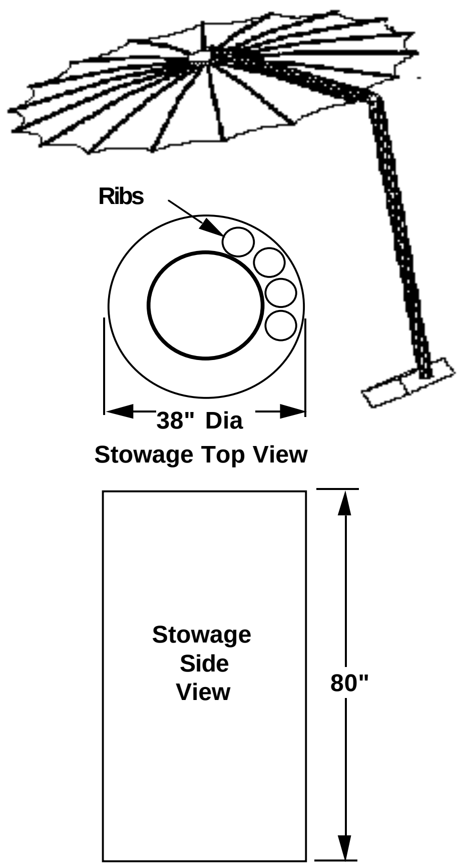
	Case	Dia Inch	RPM	Altitude Km	Taper dB	37 GHz BW deg	37 GHz Rate %
1	Low Spin Rate/Dual 37 GHz Elevation Feeds	76	28.1	830	22	0.32	84
2	Low Spin Rate/Single 37 GHz Elevation Feed	61	28.1	830	22	0.40	67
3	High Spin/Maximum Diameter	76	33.5	830	22	0.32	100
4	Optimized Packaging/Beam Efficiency	72	29.6	850	24	0.36	80





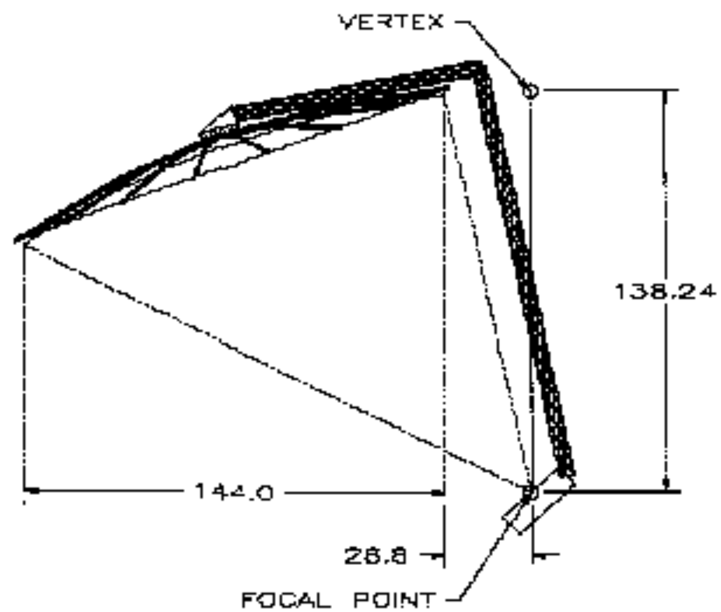
System Level Trade Studies

- Radiometer Mesh Technology Researched for Increased Diameter Feasibility and Weight Savings; Considered Developmental for Windsat



Reflector:
12'
F/D=0.4
SRP
RMS .008
Surface=Solid

Support Booms:
GFRP
Hinged/Deployable



Weight:	
Reflector	30#
SRP Surface	15#
Booms	40#
Restraints	16#
Total	101#

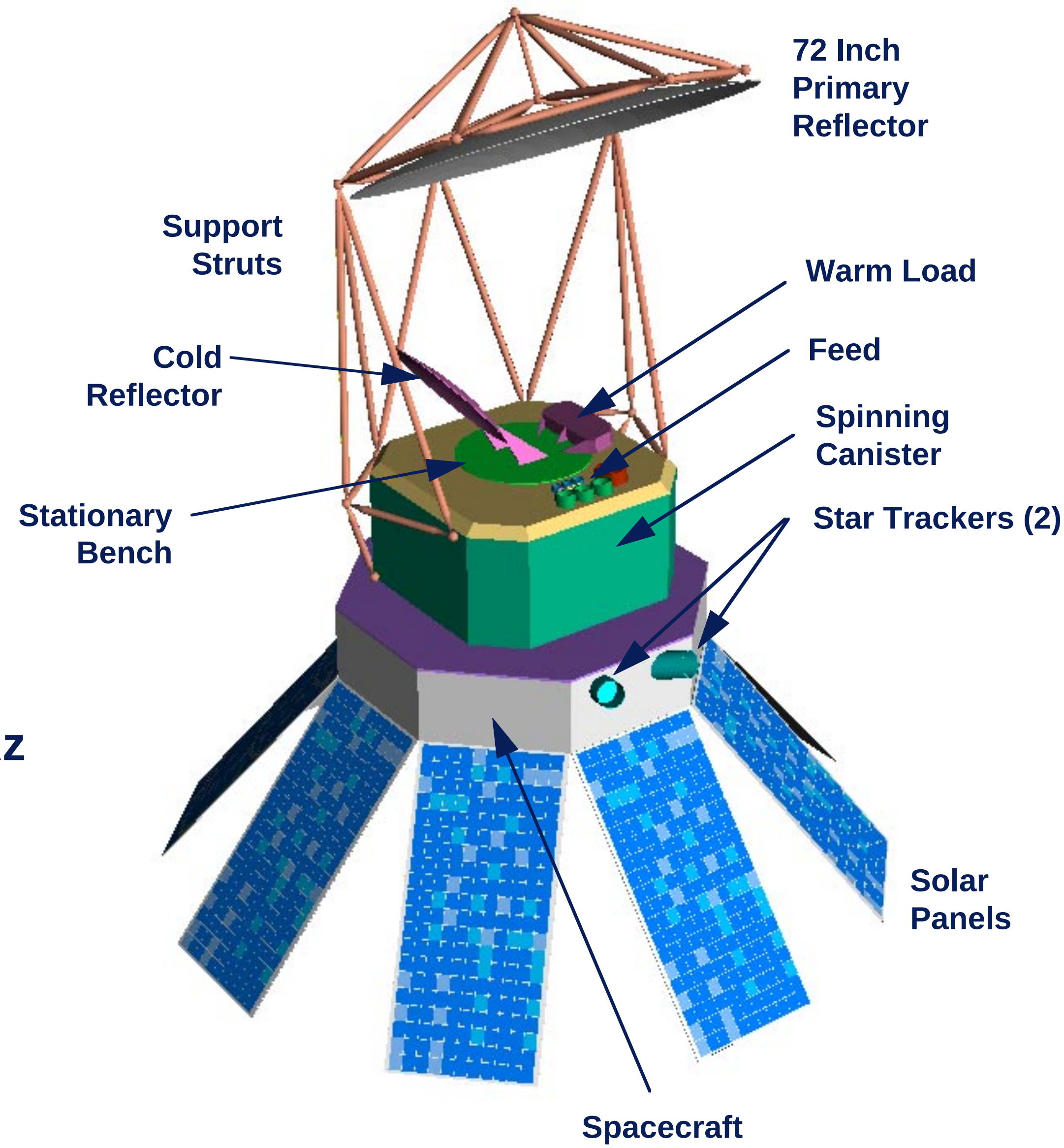
- .009" RMS (Lamda/35)
- May Not Use Mesh
  - .009" Difficult With Mesh (Cords, Ties, etc.)
  - Develop Higher Mesh Openings/Inch for Loss
- Requirements Feasible With Spline Radial Panel (SRP)
  - Deployable
  - Meets RMS and Reflectance Requirements
  - Complex and Heavier Than Mesh

Other System Level Trade Studies

- Reflector Optics Alternatives Optimized at Apex Configuration
- Cryogenics to Reduce Noise Figures to 0.5 dB Not Practical
- Solar Panel Packaging Reduces Collimated Beam Environment Noise
- Calibration Cold Reflector Alternative of Parabolic Versus Flat Plate and Size Versus Performance for Offset Feeds for Obtaining Required Accuracy

Overall Conceptual Design for Subsystem Requirements Flow and Key Features

- Maximize Primary Reflector Size With Maximum Swath
- Include Calibration and Reflector Structure Constraints
- Minimize Spacecraft T_{scene} Environment Interference
- Provide Star Tracker Attitude Field of View Clearance
- Constrain Spin Rate to Az Scene Pixel Sampling With Contiguous E1 Coverage
- No Active Thermal Control



Antenna Subsystem

W. Lippincott with H. Bartlett

Outline

- Requirements
- Trade Studies
- Design Concepts
- Supporting Analysis
  - Stokes Coupling Calculations
  - Coupling in Positive and Negative Planes of Reflector
  - Feed Design (CORHORN Program)
  - Spillover Asymmetry
  - Feed Polarization Rotation Errors
  - Range Requirements: Determination and Feasibility
- Long Lead Items
- Vendor Availability
- Implementation Plan

Windsat Antenna Derived Requirements

- **Diameter**
  - **Antenna Shall Fit Within a Cylinder of 72" Diameter in Stowed Configuration**
- **f/D Ratio of Reflector**
  - **Maximize f/D Subject to Mechanical Constraints**
- **Frequency**
  - **The Center Frequency of the Horns Shall Be: 6.8, 10.7, 18.7, 23.8, and 37 GHz**
- **Polarization Isolation Between Orthogonal Ports**
  - **Knowledge of Stokes Coupling TeRMS to < -30 dB (Theoretical or Calibrated)**
- **Beam Efficiency Goal > 95% for All Frequencies**

WindSat Antenna Design Parameters

- **Half-power Beamwidth Performance (Reflectors Feed Type)**
  - **6.8 GHz 1.91 deg. max.**
  - **10.7 GHz 1.22 deg. max.**
  - **18.7 GHz 0.7 deg. max.**
  - **23.8 GHz 0.55 deg. max.**
  - **37 GHz 0.36 deg. max.**
- **Waveguide Inputs Consistent**
  - **6.8 GHz: WR 137**
  - **10.7 GHz: WR 90**
  - **18.7 GHz: WR 42**
  - **23.8 GHz: WR 42**
  - **37.0 GHz: WR 28**

WindSat Antenna Derived Requirements

- Boresight Alignment: < 0.015 deg. (Trade Area)
  - Note: Roll Antenna 180 deg. in Alignment Procedure to Obtain This Accuracy
- Polarization Rotational Alignment Knowledge: < 0.018 deg.
- Verification Testing:
  - Measuring Co- and Cross-Pol Patterns
  - Boresight Alignment (Rotational)
  - Polarization Alignment

WindSat Antenna Derived Requirements

- VSWR ≤ 1.1 (1.02 for CP)
- Phase Center Should Remain Stable to ± 0.1 Wavelengths (Laterally) and ± 0.1 Wavelengths (Axially)
- Spillover Asymmetry Knowledge: 0.05%
- Insertion Loss (dB): < 0.30

Derived Requirements – Reflector

- **Orbital Defocus: 0.006"**

- **Manufacturing Tolerance: 3 mil RMS**

- **Thermal-Induced Roughness on Orbit: 4 mil RMS**

- **Effective Roughness (RSS of 3 and 4 Mil): 5 mil RMS**

Derived Requirements for Feed Losses to Support Allocated NEDT for Antenna Subsystem

Subsystem	6.8	10.7	18.7	23.8	37
Antenna					
Horn Loss	0.02	0.03	0.06	0.07	0.11
OMT Loss	0.02	0.03	0.06	0.08	0.12
Transmission Loss	0.12	0.03	0.05	0.06	0.09
Isolation	0.01	0.01	0.01	0.01	0.01
VSWR Mismatch	0.02	0.02	0.02	0.02	0.02
Subtotal Antenna Pre-LNA Loss	0.20	0.13	0.20	0.24	0.35
Allocated Loss	0.30	0.30	0.30	0.30	0.40
Margin (dB)	0.10	0.17	0.10	0.06	0.05

Derived Requirement:
Beam Efficiency at 37 GHz

- **Roughness (5 mil RMS): 96.2%**
- **Spillover (24 dB Taper): 99.0%**
- **Crosspolarization: 99.75%**

Total Efficiency: 95%

Roughness Efficiency [$e^{-(4\pi\varepsilon/\lambda)^2}$] Increases to 99.1% at 18 GHz

Trade Study: Horn Configuration

- **Several Horn Configurations Were Considered and Rejected Due to Either Mechanical Considerations, Polarization Purity, Beam Assymetry, or Earth Incidence Angle Requirements**
  - **Multiple Polarization Horns (5 Horns vs. 11; Joint Receiver/Antenna Trade)**
  - **Multi-Frequency Horns (Higher Insertion Loss, Separation 37 GHz Phase Centers, Low Beam Efficiency)**
- **Current Horn Configuration Was Developed to Optimize Polarization Purity Within the Desired Constraints**
- **CP and 45 deg. Horns May Be Interchanged Depending on the Outcome of Further Analysis**

Trade Study: Horn Types

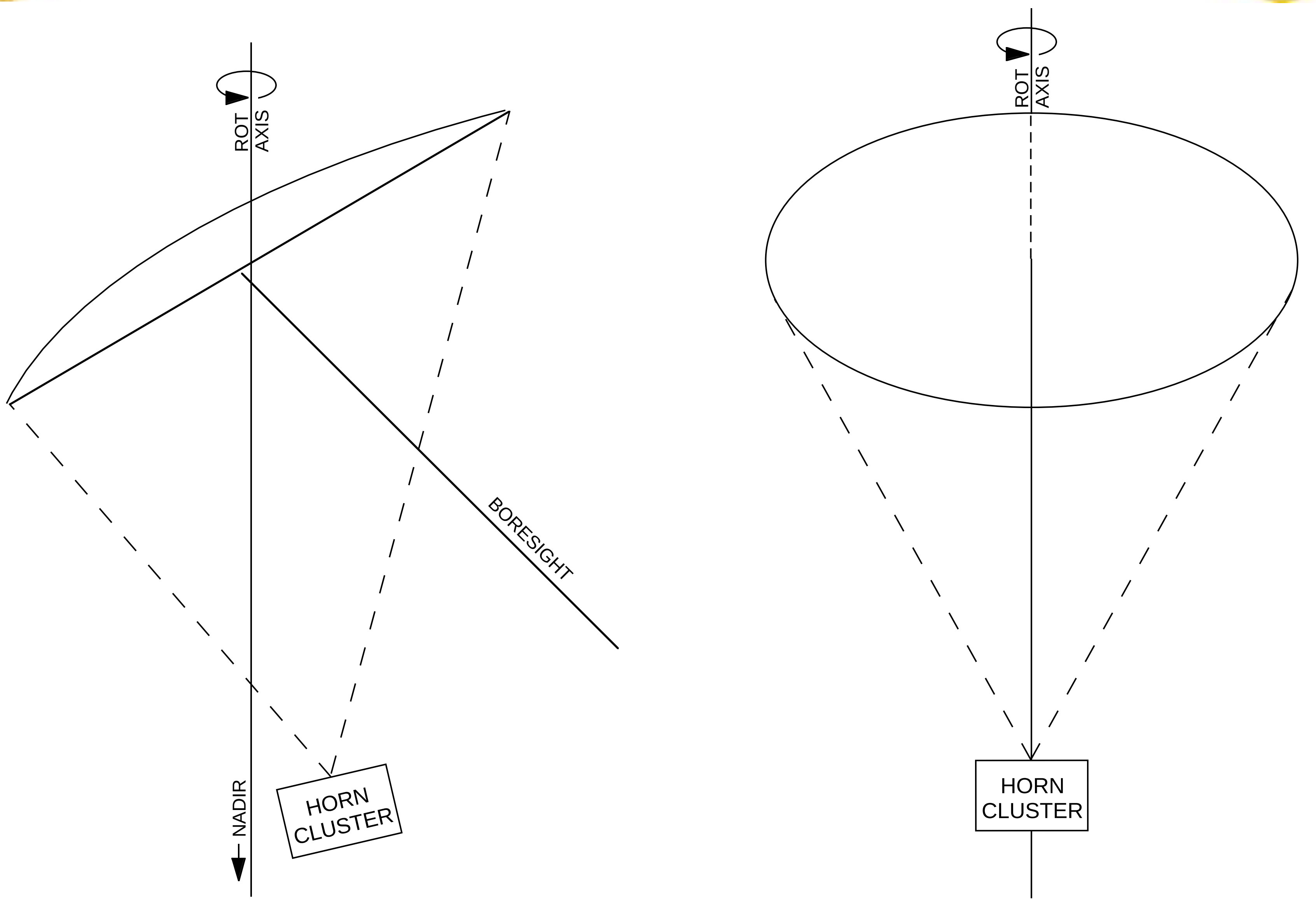
- Potter Horn Was Considered and Rejected Due to Beam Assymetry
- Tri-Mode Horn Was Considered and Rejected Due to Increased Squint in Elevation Lobes Although Improvement in Cross-Pol in the Azimuth Plane Was Achieved
- Multi-Frequency Horns Were Considered and Rejected Due to Problems With Beam Assymetry, Increased Insertion Loss, and Extreme Separation of 37 GHz Phase Centers
- Single-Frequency/Multi-Polarization Horn Was Rejected Due to Desire to Avoid Extra Calibration in Receiver
- Circular Corrugated Horns Are Optimum Due to Their Excellent Beam Symmetry and High Beam Efficiency (Low Spillover)

Trade Study: Main Reflector

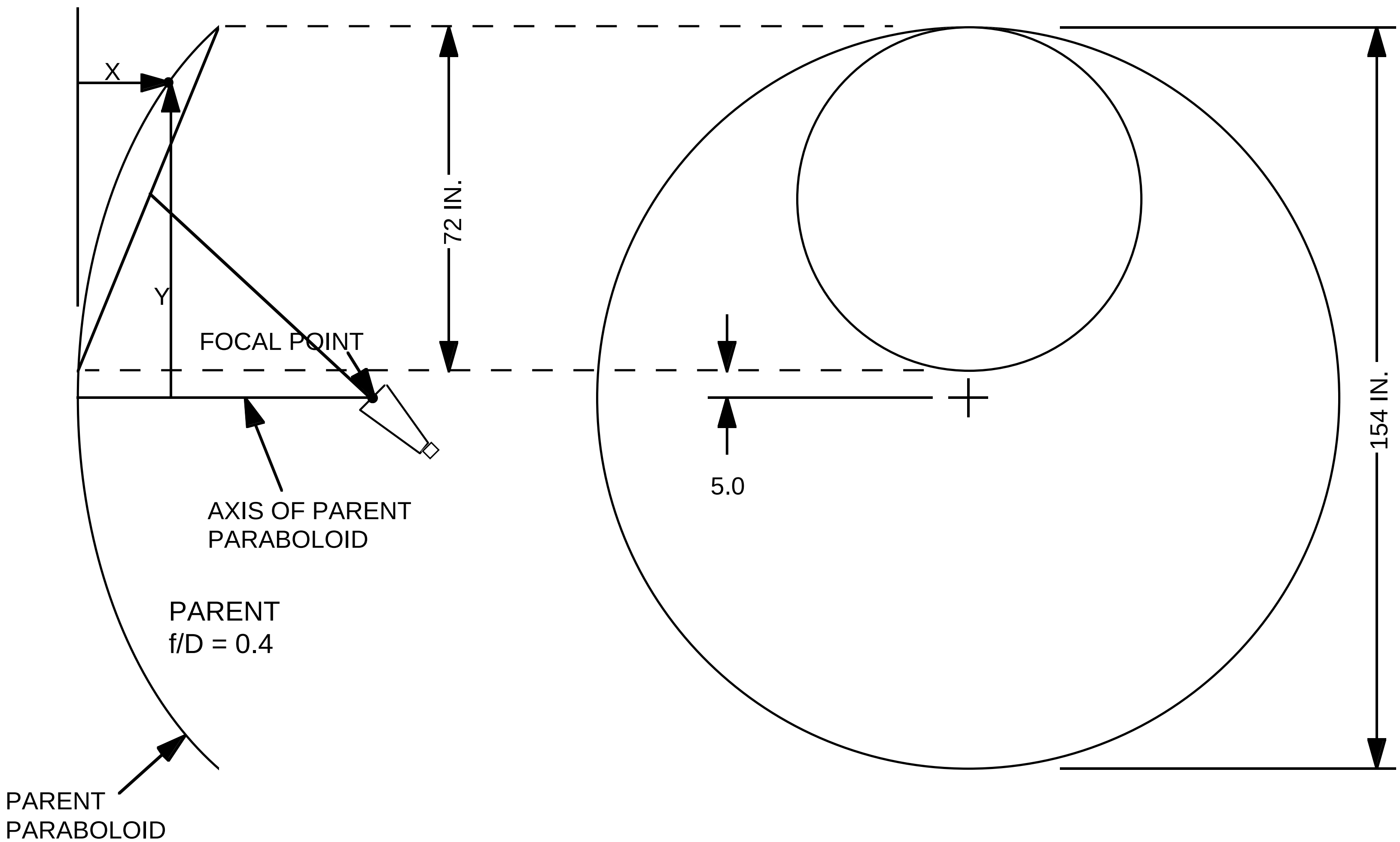
- **Cassegrain, Folded Optics and Apex Feed Designs Were Considered; Cassegrain and Folded Optics Designs Were Discarded Due to Low Beam Efficiency, Antenna Blockage, Spillover Viewing Earth**

- **Survey Was Done of Several Companies Capable of Manufacturing the Main Reflector; Considerations Are Manufacturing Tolerances, Experience, Reputation, Lead Time, and Cost**

Design Concept – Apex Feeds



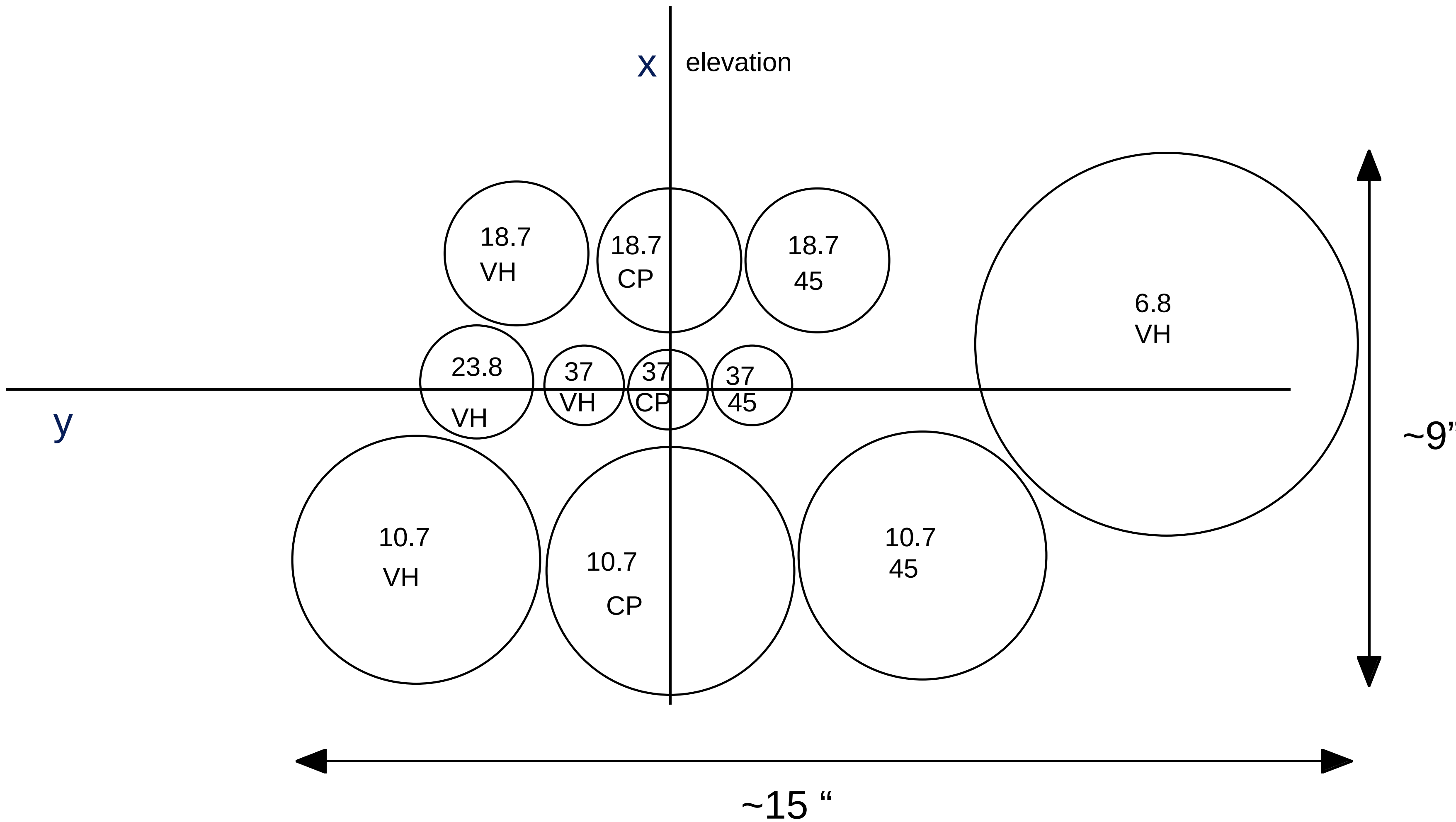
Offset Parabolic Reflector



PARABOLOID EQUATION
$y^2 = 4 f X$
F (FOCAL LENGTH) = 61.6 IN.

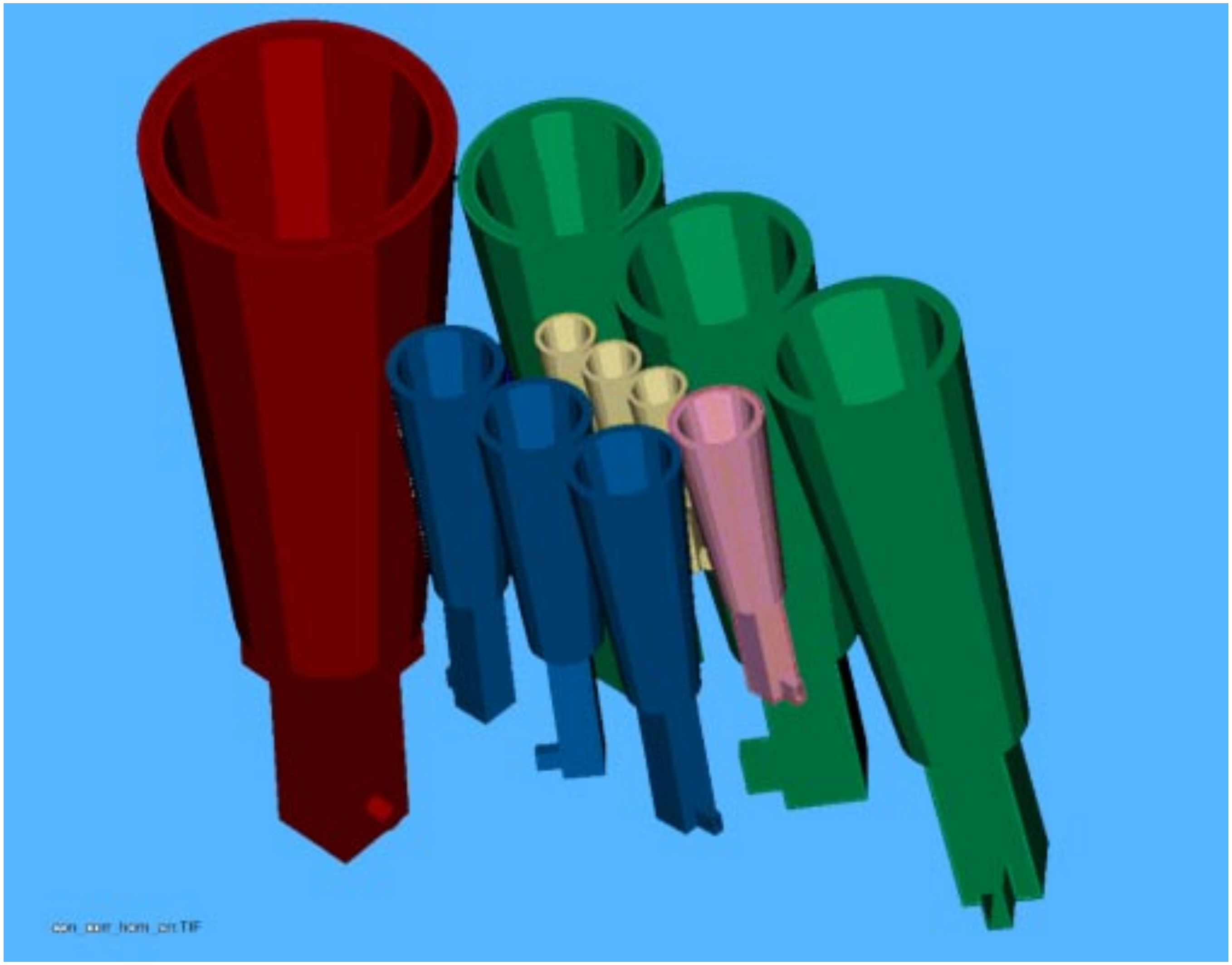
ANGLE TO BOTTOM OF DISH IS 4.49 DEG
ANGLE TO TOP OF DISH IS 64.011 DEG

Design Concept –
Horn Cluster Configuration



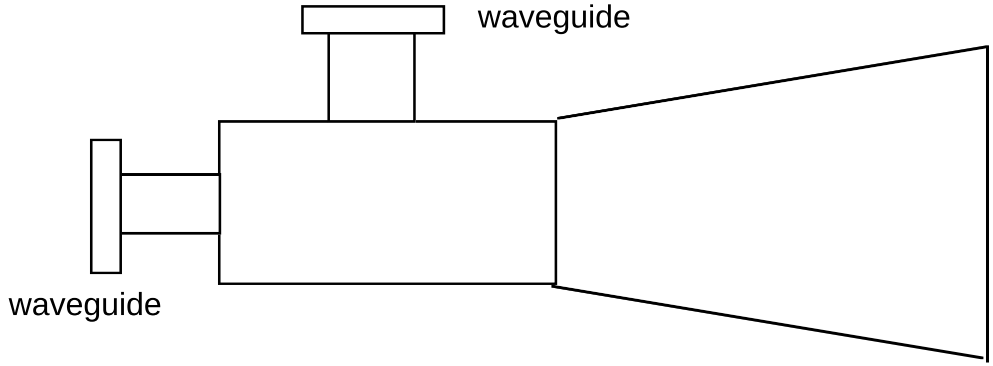
CP and 45 Deg. Horns May Be Interchanged Based on Further Calibration Analysis

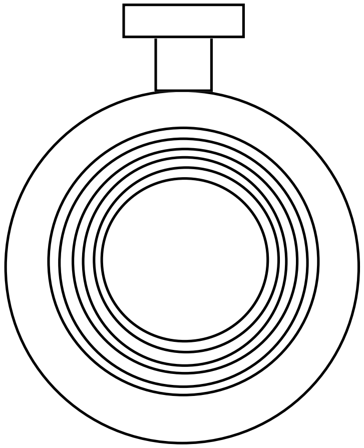
Conical Corrugated Horn Array



5 Degree Corrugated Conical Horns – MEC Dimensions

Frequency (GHz)	Outer Diameter (inches)	Flare Length (inches)
6.8	6.2	13.4
10.7	4.0	10.0
18.7	2.3	5.75
23.8	1.9	4.5
37	1.2	2.9



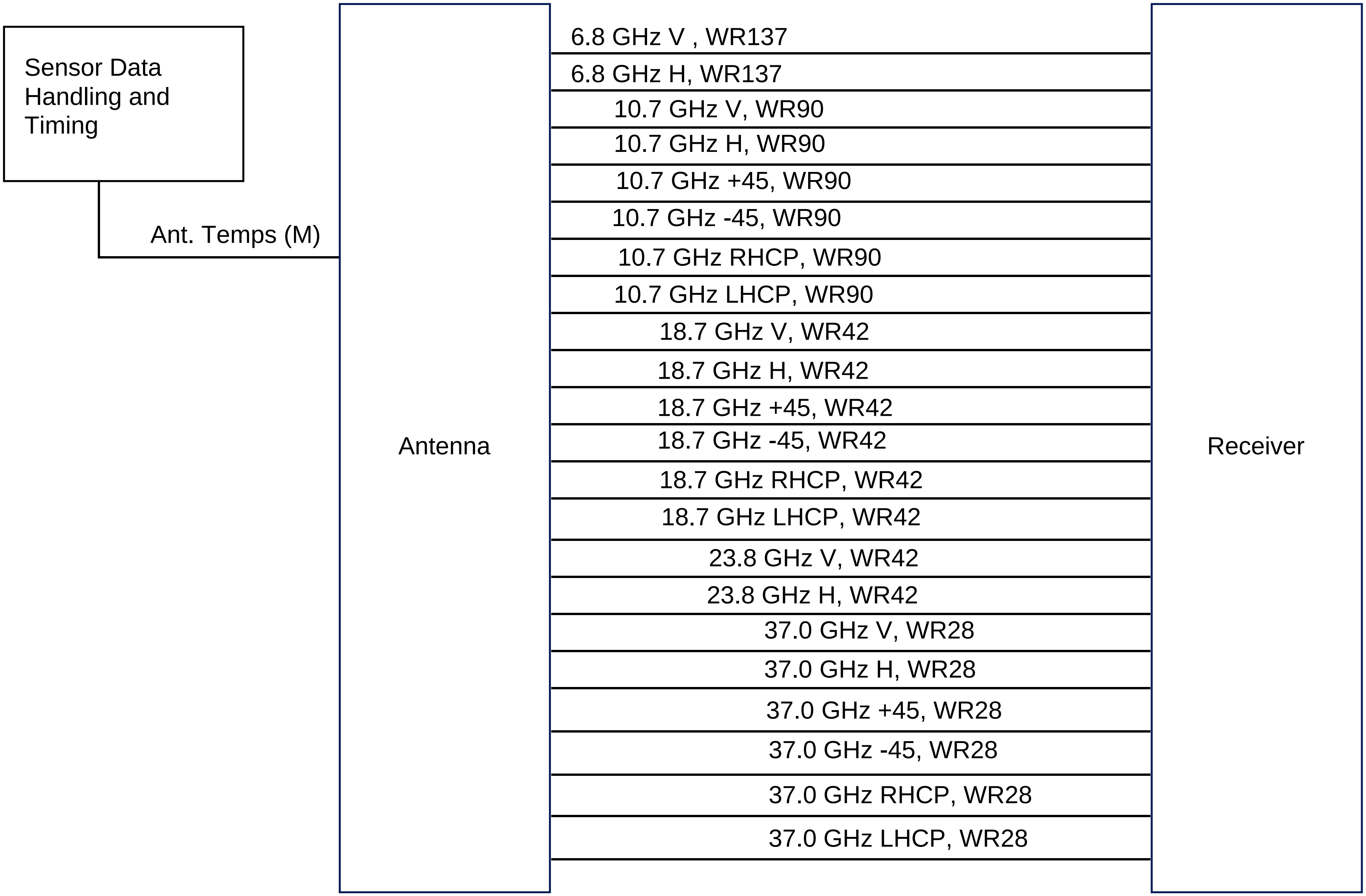


XY Coordinates of Horns

Frequency (GHz)	Polar-ization	x-position (elevation) (in)	y-position (in)
6.8			
10.7	VH	3.025	4.1
10.7	45	2.9	0.0
10.7	CP	3.025	-4.1
18.7	VH	-2.057	2.4
18.7	45	-2.1	0.0
18.7	CP	-2.057	-2.4
23.8			
37.0	VH	0.012	1.25
37.0	45	0.0	0.0
37.0	CP	0.012	-1.25

Allows 0.1" Horn Separation (0.05" for 37 GHz)

Design Concept: Interface Diagram



Stokes Coupling Inverted Matrices for Horn Cluster Configuration*

Stokes Coupling (dB) 10.7 GHz:

0.01	-26.0	-29.0	-30.7
-26.1	0.01	-29.3	-30.7
-26.3	-26.0	0.02	-44.2
-27.9	-27.6	-38.2	0.0

Stokes Coupling (dB) 18.7 GHz:

0.01	-24.9	-33.2	-28.1
-24.9	0.01	-32.5	-28.2
-29.5	-30.2	0.03	-47.6
-25.3	-25.1	-38.1	0.0

Stokes Coupling (dB) 37 GHz:

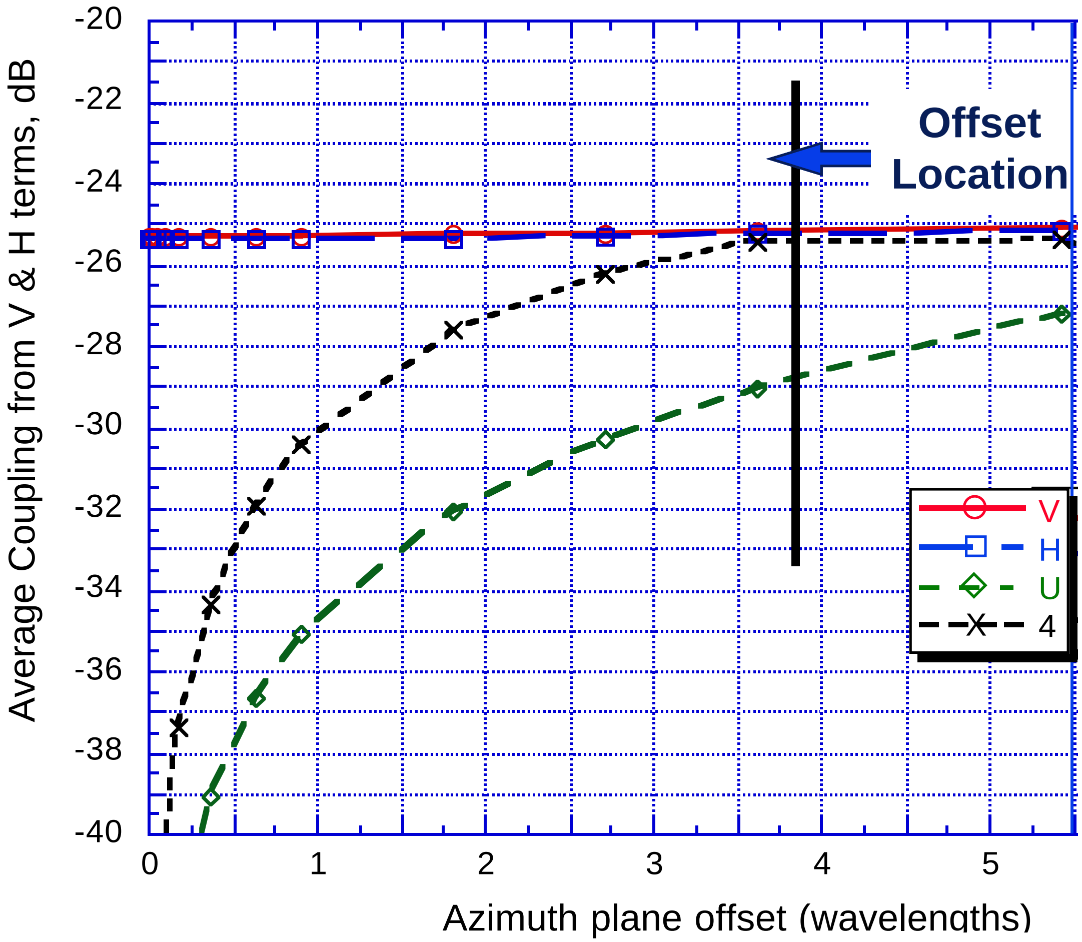
0.01	-25.5	-36.5	-28.2
-25.5	0.01	-37.1	-28.2
-34.1	-33.4	0.02	-50.0
-25.3	-25.1	-42.4	0.0

$$\vec{T}_{scene} = \overline{\overline{M}}^{-1} * \vec{T}_{antenna}$$

$$\overline{\overline{M}}^{-1} = \begin{bmatrix} C_{vv} & C_{vh} & C_{vu} & C_{v4} \\ C_{hv} & C_{hh} & C_{hu} & C_{h4} \\ C_{uv} & C_{uh} & C_{uu} & C_{u4} \\ C_{4v} & C_{4h} & C_{4u} & C_{44} \end{bmatrix}$$

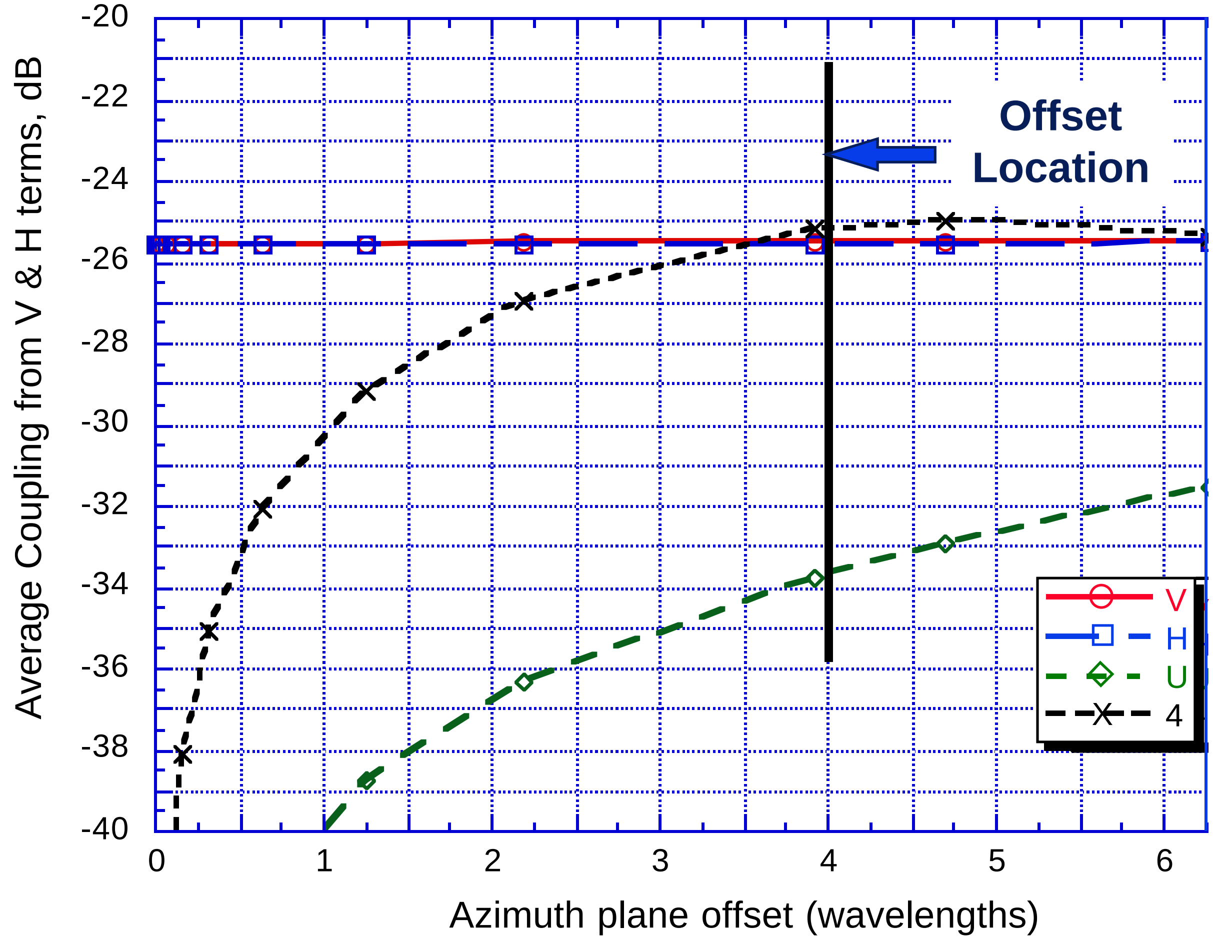
*** Putting Both +45/-45 and CP Horns Are in Offset Location (for Analysis Purposes Only; Normally, the Horn With the Central Location Will Have Negligible Coupling Terms)**

Antenna Cross Term Coupling versus Offset Distance (10.7 GHz case)



- **The Coupling Terms Represent Reflector Generated Cross-Pol; They Can Be Reduced by Using a Larger f/D Reflector, However, Mechanical Constraints Limit f/D to 0.4 (on Parent Paraboloid)**

Antenna Cross Term Coupling Versus Offset Distance From Poe Code (37 GHz Case)



Note: Range Measurements on Test or Flight Reflector Will Include Moving Feeds to Various Locations Both to Verify the Poe Model and Also Estimate Range Accuracy

Position Accuracy for Centered Position Feeds

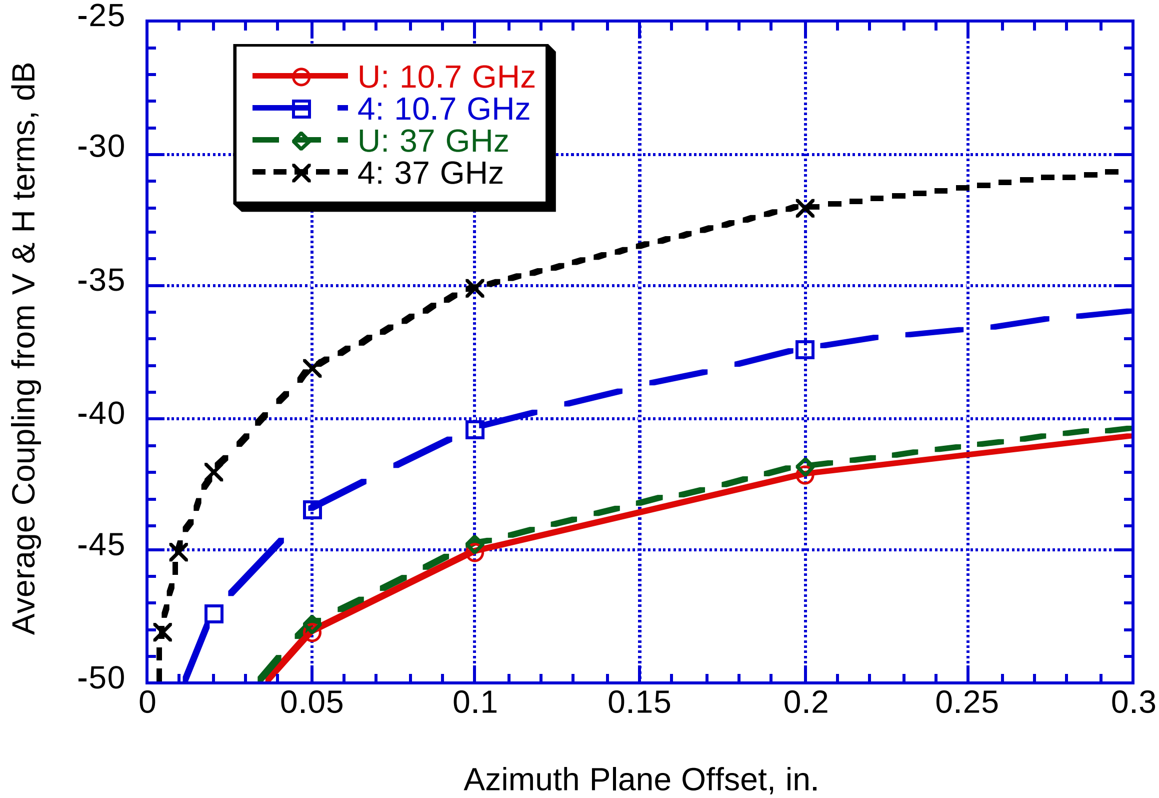


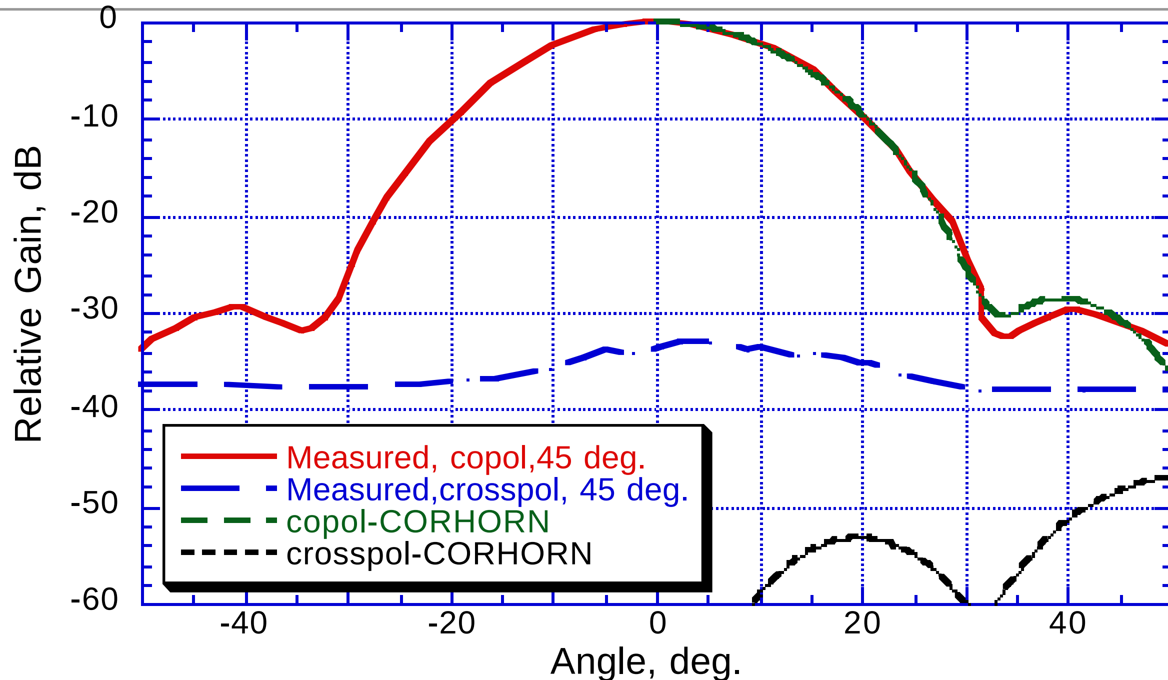
Chart Indicates Tolerances (for -40 dB Coupling):

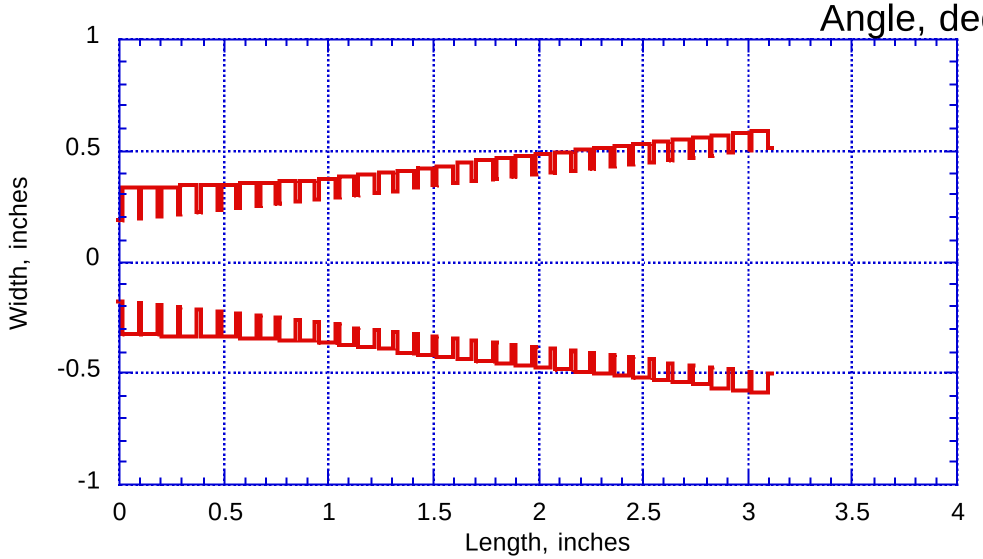
- **For 10.7 GHz (U) Horn Should Be < 0.3”**
- **For 10.7 GHz (4) Horn Should Be < 0.1”**
- **For 37 GHz (U) Horn Should Be < 0.3”**
- **For 37 GHz (4) Horn Should Be < 0.03”**

Feed Design

- CORHORN Program Was Purchased From Antenna Software Limited to Model Complex Patterns of Circularly Symmetric Corrugate Horns

CORHORN* Modeling vs. Measured Data





- 36.5 GHz Circular Corrugated Horn
- 45 deg.-Plane, 6 deg. Flare Angle
- Reflector Half Cone angle = 29.76o
- MEC Model MF390-160-4
- CORHORN Calculated VSWR = 1.03

*** Antenna Software, Ltd.**

Feed Polarization Rotation Errors

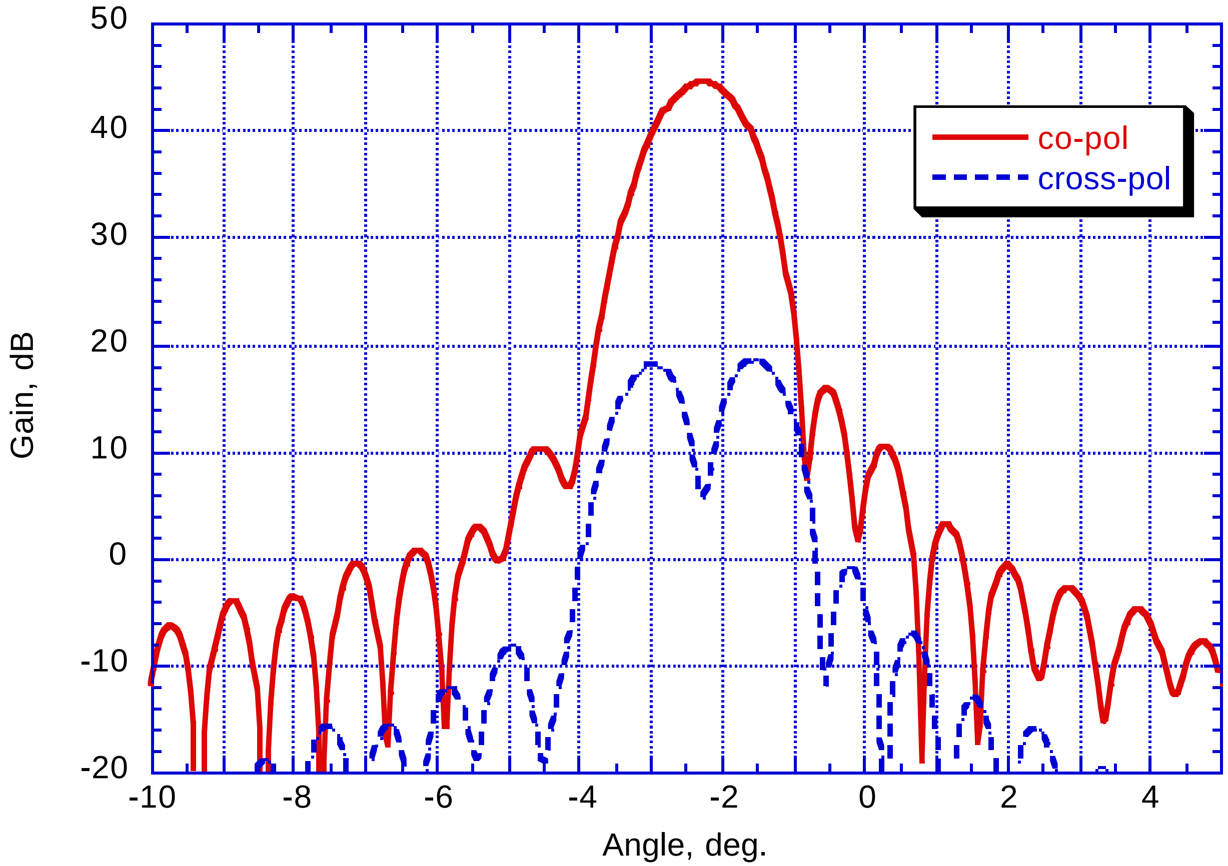
Centered Feed Horns

Polarization Rotation, θ Degree	3rd Strokes (+/– 45 Degree) (V & H Into U)
0.01	-34.5 dB
0.02	-31.5 dB
0.05	-27.6 dB
0.1	-24.6 dB

Approximation of Antenna Range Error Impact on Stokes Parameters

- Using POE Code, Calculate Stokes Coupling Parameters As a Function of Feed Offset
- Using OSUREF Code, Calculate Cross-Pol Lobe Imbalance As a Function of Feed Offset
- Combine to Produce Relationship of Stokes Coupling Parameters to Cross-Pol Lobe Imbalance
- Knowing Impact of Antenna Range Cross-Pol and Reflections on Cross-Pol Lobe Imbalance, Use Above to Determine Impact on Stokes Coupling Parameters
- More Direct Calculation Will Be Made After POE Code Is Modified to Accept Externally-Generated Antenna Patterns

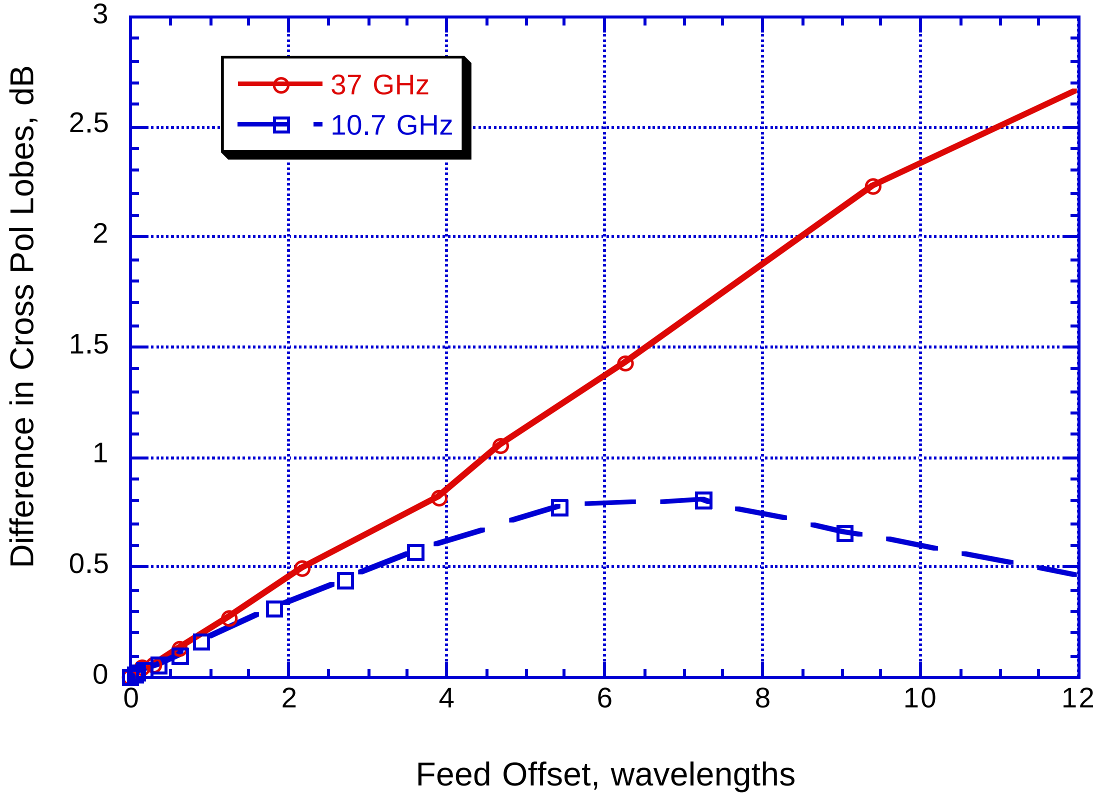
OSUREF Runs



10.7 GHz, 3" Offset, 0.44 dB Difference in Height of Cross-Pol Lobes

- **Cross-Pol Lobes for Centered Horns Are 180 Deg. Out of Phase, and Cancel Each Other Out; for the Offset Horns, Cross-Pol Lobes Are Imbalanced, and Do Not Cancel Each Other Out Completely; Magnitude of Stokes Coupling Terms Are Directly Related to Cross-Pol Lobe Imbalance, Which to a First Order Can Be Approximated by the Difference in Height of the Cross-Pol Lobes**

OSUREF Code Runs to Determine Range Accuracy Requirements



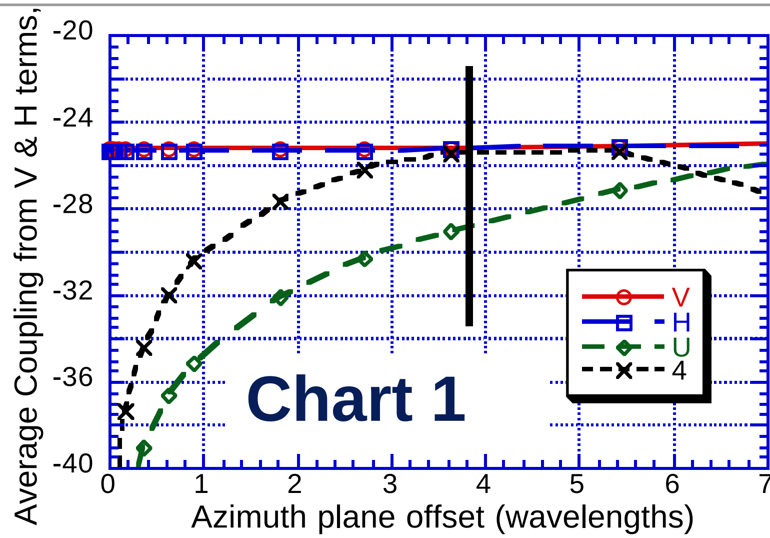
Slope at 3 Wavelengths Offset:

10.7 GHz: 0.14 dB/λ

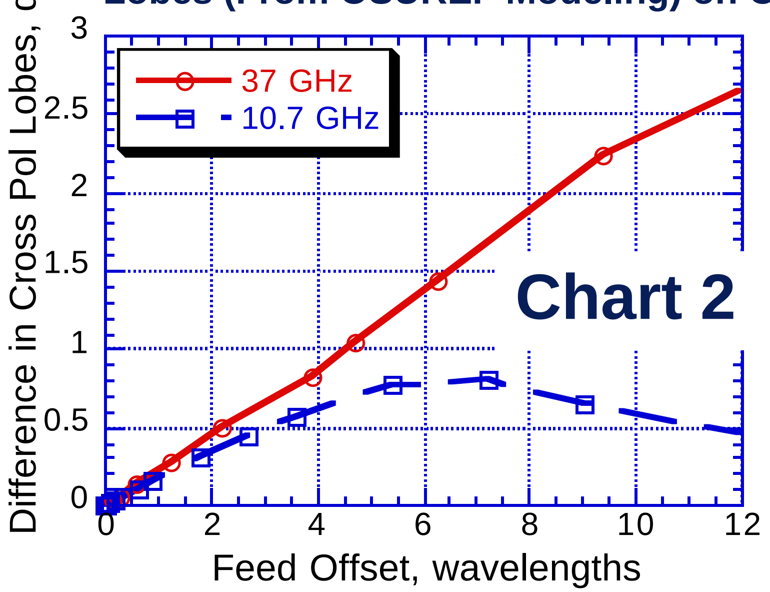
37.0 GHz: 0.19 dB/ λ

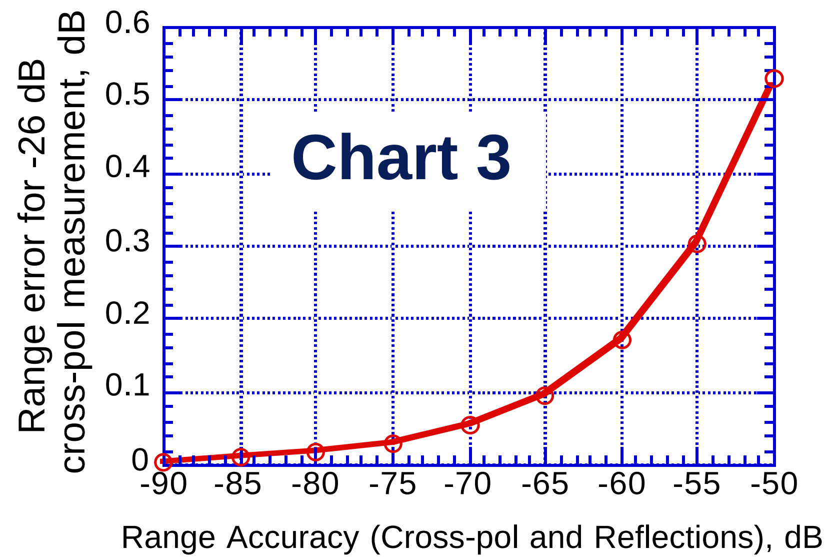
Approximation Only Valid to ~ 6 λ , Because at This Point, Cross-Pol Lobe Width Differential Increases, and Need to Integrate Area to Get Valid Results

Range Accuracy Determination



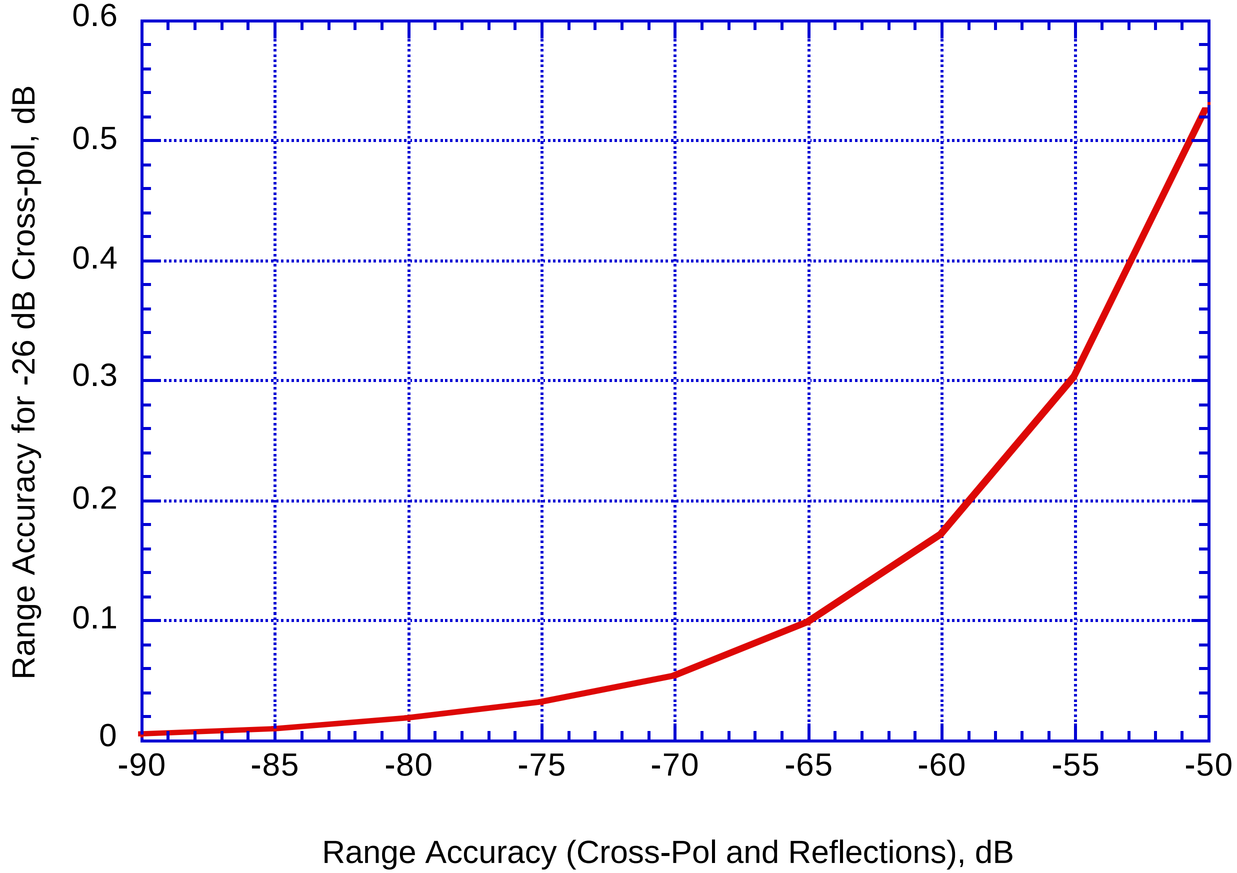
1. **Find Coupling at 4λ Offset on Chart 1 (From Poe Code)**
2. **Determine Allowable Error in dB for -30 dB Accuracy**
3. **Using Chart 1, Map Allowable Error in dB to Error in Offset (in Wavelengths)**
4. **Convert Offset Error to Difference in Cross Pol Lobes (From OSUREF Modeling) on Chart 2**





5. **Difference in Cross Pol Lobes Corresponds to Range Accuracy Needed in Chart 3; Map Range Error to Range Accuracy for Final Result**

Range Resolution vs. Range Accuracy (Based on Measurement Accuracy of -26 dB Cross-Pol)



Determination of Range Accuracy Needed to Achieve -30 dB Accuracy of Cross Pol

Offset λ	Freq. GHz	Term	Coupl. Level dB	-30 dB Accuracy (dB)	Delta λ	Slope from OSU-REF Code dB/λ	Allowable range error (at -26 dB level) dB	Range meas. accuracy (xpol & reflections) dB
3	10.7	U	-28.8	+/-4.3	+/-2.7	0.14	0.38	-53
3	10.7	4	-25.2	+/-1.5	+/-1.5	0.14	0.20	-59
3	37	U	-33.6	+/-5	+/-6	0.19	1.14	-44
3	37	4	-25.2	+/-1.5	+/-1.5	0.19	0.28	-54

Note: Assuming Both 45 Deg. and CP Horns Are Offset (for Analysis Only)

Far-Field Antenna Range

- **Antenna Alignment**
  - **Boresight, Polarization and Cross-Pol Lobes**
- **Calibration of Stokes Coupling Terms**
  - **Measure Co-Pol and Cross-Pol Patterns, Amplitude, and Phase; Insert in Poe Code to Determine Coupling Parameters**

Antenna Alignments

- **Boresight Alignment- Lateral Position of Feed Horns Must Be Adjusted to Correctly Orient Antenna Boresight in Spacecraft Coordinate System**

- **Polarization Alignment - Rotation of Feed Horns Must Be Adjusted to Correctly Orient Polarization Vector in Spacecraft Coordinate System**

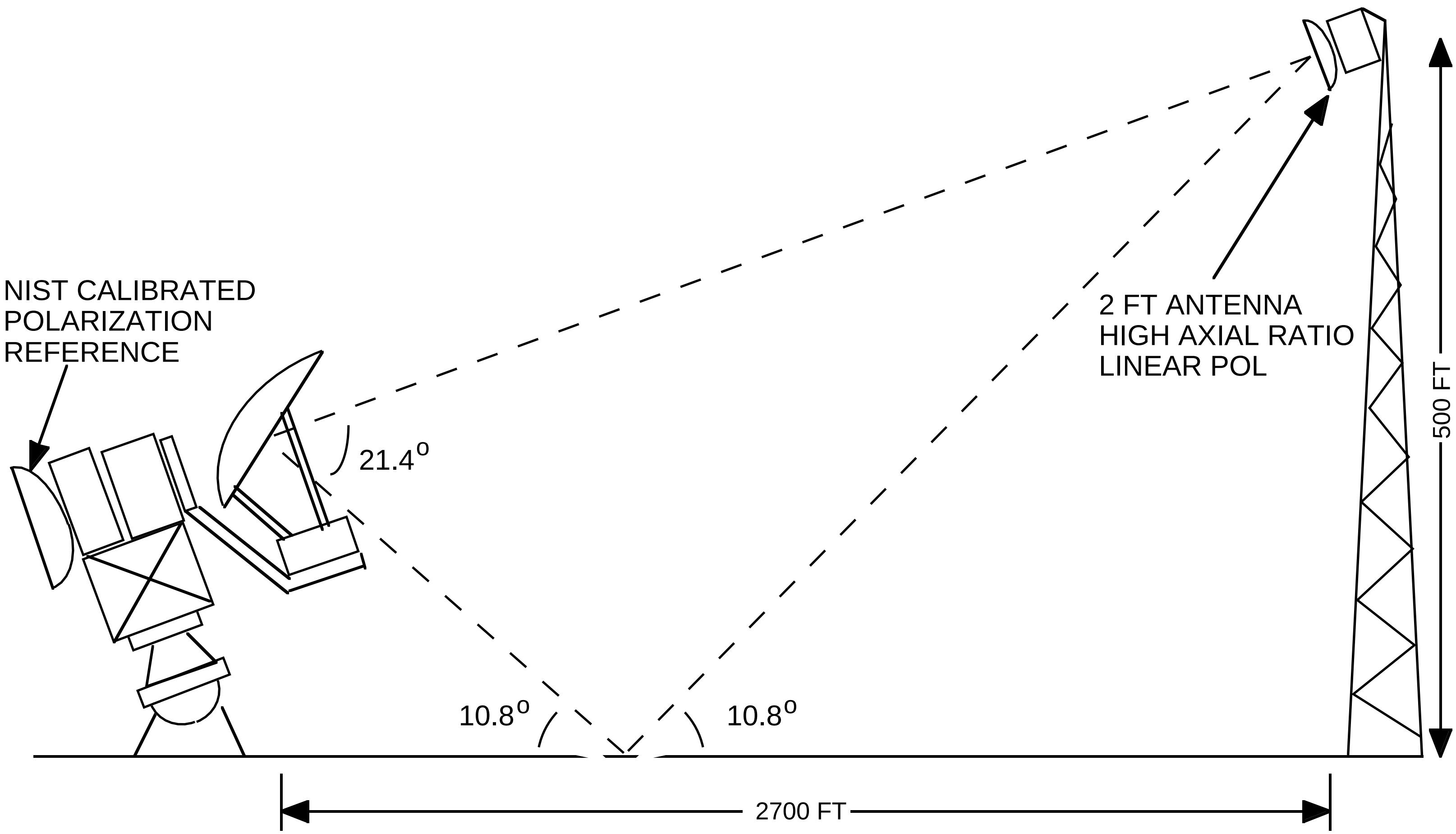
- **Reflector Cross-Pol Lobe Alignment - Rotation of Reflector Must Be Adjusted to Correctly Orient Cross-Pol Lobe Symmetry Plane in Spacecraft Coordinate System**

Precision Antenna Range Requirements

	Reflections	Cross-pol
Boresight Alignment	-45 dB [1]	-20 dB [2]
Polarization Coupling Cal.	-65 dB [3]	-65 dB [3]
Polarization Coupling Cal. with pulse gating	-100 dB [4]	-59 dB

1. **Boresight alignment by rotation about boresight axis and overlaying patterns. (Slope at 20 dB down point on 10.7 GHz pattern is 0.029 deg/dB; convert -45 dB down signal to voltage and add to -20 dB signal, convert back to dB and take the difference between that and -20 dB. Multiply by slope to get the error in boresight alignment (which should be less than 0.015 deg.) This requirement decreases to -34 dB for 37 GHz.**
2. **Cross polarization has negligible effect on boresight alignment.**
3. **Worse case addition of -65 dB reflection error and -65 dB cross pol error gives -30 dB effect on Poe matrix coupling coefficients.**
4. **Gating used to reduce impact of range reflections.**

Candidate Antenna Range



GATING SYSTEM USED TO REDUCE EFFECT OF REFLECTIONS TO -100 DB LEVEL
(REFLECTION PATH LENGTH IS 2.6 NANOSEC LONGER THAN DIRECT)

NIST CALIBRATED POLARIZATION REFERENCE CALIBRATED TO 30 ARC SECONDS
USED TO ADJUST INCOMING POLARIZATION

Antenna Range Measurement Feasibility (Is -59 dB Cross-Pol Error Obtainable?)

- Navy China Lake Facility Has a 4000 Ft. Range Which Uses Pulse Gating Equipment Manufactured by Lintek to Obtain Very Low Reflections and Cross Polarization; Cross-Polarization Levels Better Than -60 dB Have Been Measured on That Range

- JPL 3000 FT Range Reported to Be Capable of -60 dB to -70 dB Cross Polarization Measurement but No Documentation Is Available

Implementation Plan

- **Long Lead Items**
  - **Reflector (8-12 Months)**
  - **Horns (4-6 Months)**
- **Vendor Availability**
  - **Reflector: Composite Optics Is Available**
  - **Horns: Microstar or MEC Are Both Available**

Implementation Plan

- Finalize Design Parameters
- Test Antenna Range With Spare Reflector
- Build Horns
- Build Reflector
- Characterize Horns in Anechoic Chamber
- Assemble Reflector/Horn Feeds
- Characterize Reflector With Horn Feeds on Outdoor Range
- Compare Modeling Results With Outdoor Chamber Data

Payload Warm/Cold Calibration Subsystem

H. Bartlett, M. Smythers, W. Lippincott, T. Gutwein, P. Gaiser

Allocated Calibration Requirements

- **Requirements**
  - **Single Receiver Calibration Accuracy** **0.75 K**
  - **Difference Channel Accuracy** **0.25 K**
  - **To Be Allocated Among:**
    - **Warm Load, Cold Load, System Non-Linearities, Gain Drift Between Calibrations, Residual Sidelobe Contamination**
- **Error and Sources**
  - **Difference Channel Errors Result From Non-Common (Independent) Errors**
    - **Examples: Polarization Dependence of Warm Load Emissivity; Different Channel Non-Linearity; Polarization Dependent Sidelobes**
  - **Independent Error Sources Are RSS'ed Together Because Sign of Errors Is Unknown**

Calibration Error

- **Calibration Error Is Weighted Combination of Several Error Sources**
  - **Error Depends on Input Signal; Optimize Allocations So That Maximum Errors Are Acceptable**
- **Some Errors Will Cancel When Channels Are Differenced**

$$E_{cal} = xE_{wl} + (1 - x)E_{cl} + 4(x^2 - x)E_{nl} + T_{sl} + \Delta T_G$$

$$x = \frac{V_{scene} - V_{cl}}{V_{wl} - V_{cl}}$$

E_{wl} = warm load error

E_{cl} = cold load error

E_{nl} = system nonlinearities

T_{sl} = residual sidelobe contribution

ΔT_G = gain drift between calibrations

Derived Calibration System Requirements

	Bias	Random	Common/Independent
Warm Load			
Emissivity < 1.0	- 0.15		Both
Temperature Drift		± 0.05	Common
Measurement Accuracy		± 0.10	Common
Temperature Gradient		± 0.10	Common
Warm Total	**- 0.15**	± **0.15**	
Cold Load			
Tcosmic Uncertainty		± 0.02	Common
Earth in Sidelobes	+ 0.25	± 0.14	Both
Spacecraft in Sidelobes	+ 0.15		Both
Cold Total	**+ 0.4**	± **0.15**	
Nonlinearities (max)[1]	**- 0.5**	± **0.10**	Independent
Gain Drift[1]		± **0.06**	Independent
Sidelobe Energy2		± **0.15**	Independent

[1] Receiver
[2] Antenna

Warm Load Derived Requirements

- **Interfaces to Other Systems**
  - **Physical Temperature Data**
- **Requirement**
  - **Bias** **- 0.15 K**
  - **Random** **± 0.15 K**
  - **Independent** **± 0.10 K**

Warm Load	**Bias**	**Random**	**Common/Independent**
Emissivity < 1.0	-0.15		Both
Temperature Drift		± 0.05	Common
Measurement Accuracy		± 0.10	Common
Temperature Gradient		± 0.10	Common
Warm Total	**-0.15**	± **0.15**	

Warm Load Design Concept

- Radiometric Absorber Remains Stationary As Feed Horns Pass Below Once Per Scan
- Conceptual Warm Load Is 10x10x6 (inches) With Square Pyramids
  - Ensures Excellent Coupling of Entire Feed Horn Array
  - Minimum of Four Calibration Samples at 6.8 GHz; Over Twenty Samples at 37 GHz
- Mass - 12 Pounds
- Passive Thermal Control - Minimize Gradients and Noise
- Platinum Resistor Thermometers (PRT) Temperature Sensors

Warm Load Implementation Plan

- Warm Load Will Be Contracted Out
- Lead Time Is Approximately 6 Months
- Unique Test Equipment
  - Modifications to Existing Differential Radiometer to Measure Warm Load Emissivities, Variabilities
- Vendor Availability
  - ZAX Millimeter Wave, GenCorp Aerojet (?)
  - Investigating Availability of MIMR Hardware

Warm Load Concerns/Trade Studies

- Effect of Non-Normal Incidence Angle for Some Feeds (10.7 and 18.7 GHz)
- Emissivity Dependence on Viewing Geometry With Square Pyramids
- Trades to Be Completed
  - Square Pyramids vs. Cones: Reduce Rotational Effects
  - Flat Baseplate vs. Contoured: Allow All Feeds Normal Viewing Angle
  - Material Selection: Mass vs. Thermal Conductivity, and Specific Heat
- Trades to Be Completed by 15 March 1998

Cold Load Derived Requirements

- **< 0.13 % of Energy Received From Earth**
  - **(.0013 * 300) = 0.39 deg. K Max (0.25 ± 0.14)**
- **< 0.15 K Energy Received From Spacecraft**
- **Reflector Sized to Minimize Scan Occlusion**
- **Surface Tolerance: 3 Mil**
- **VDA (Vapor Deposit Aluminum) Surface**

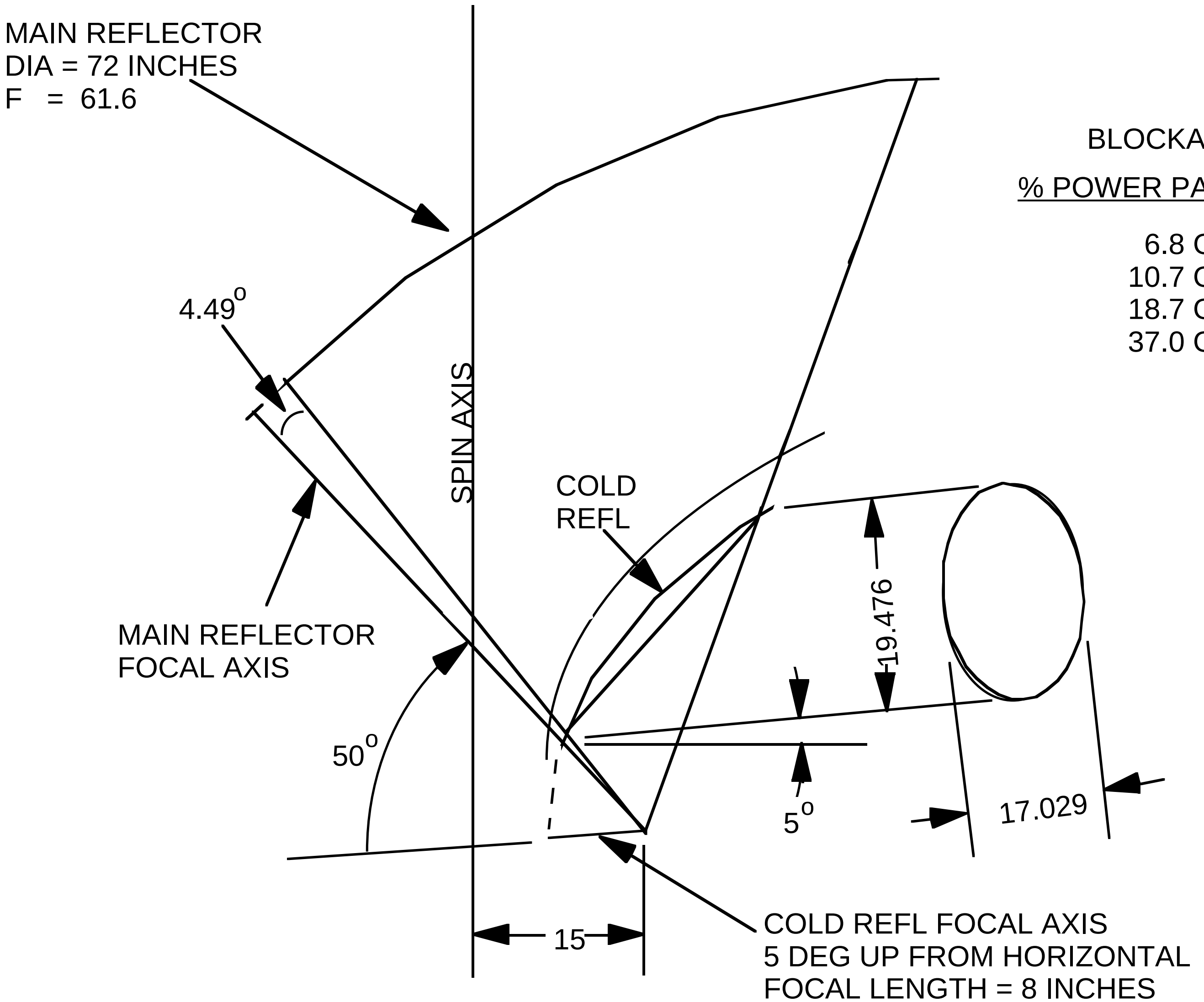
Cold Load Trade Studies

- **Cold Reflector Size Versus Swath Width**
- **Cold Load Pointing Angle Versus Energy Projected Onto Earth (Cold Load Temperature)**
- **Occlusion Versus Focal Length Distance From Spin Axis**
- **Other Type of Reflectors**

Cold Load Interfaces to External Subsystems

- **Only Mechanical Interfaces**

Design Concept: Cold Load Reflector



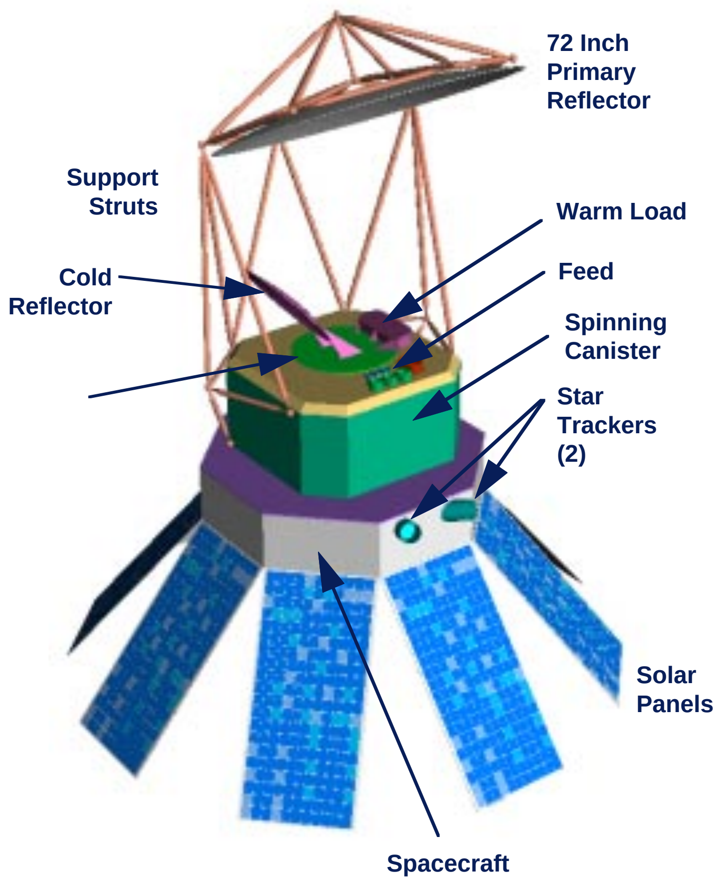
BLOCKAGE OCCLUSION = 162°

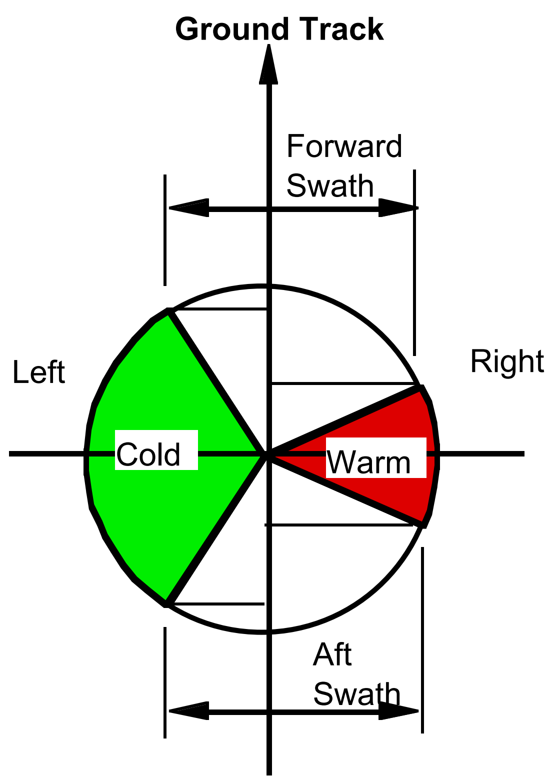
<u>% POWER PATTERN EARTH DIRECTED</u>

6.8 GHZ	0.035%
10.7 GHZ	0.044%
18.7 GHZ	0.025%
37.0 GHZ	0.035%

Subsystem Summary Level Budgets

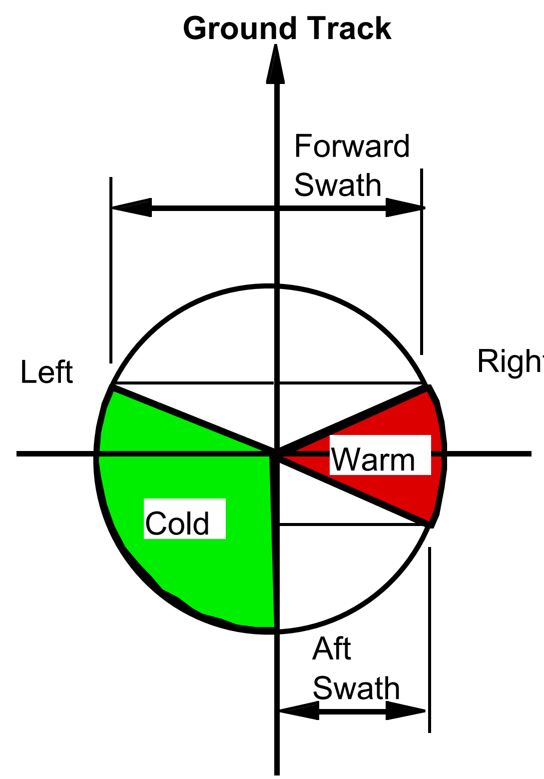
- **Example Subsystem Swath Allocation Among Reflector, Warm, and Cold Load**





Symmetrical Cal Case

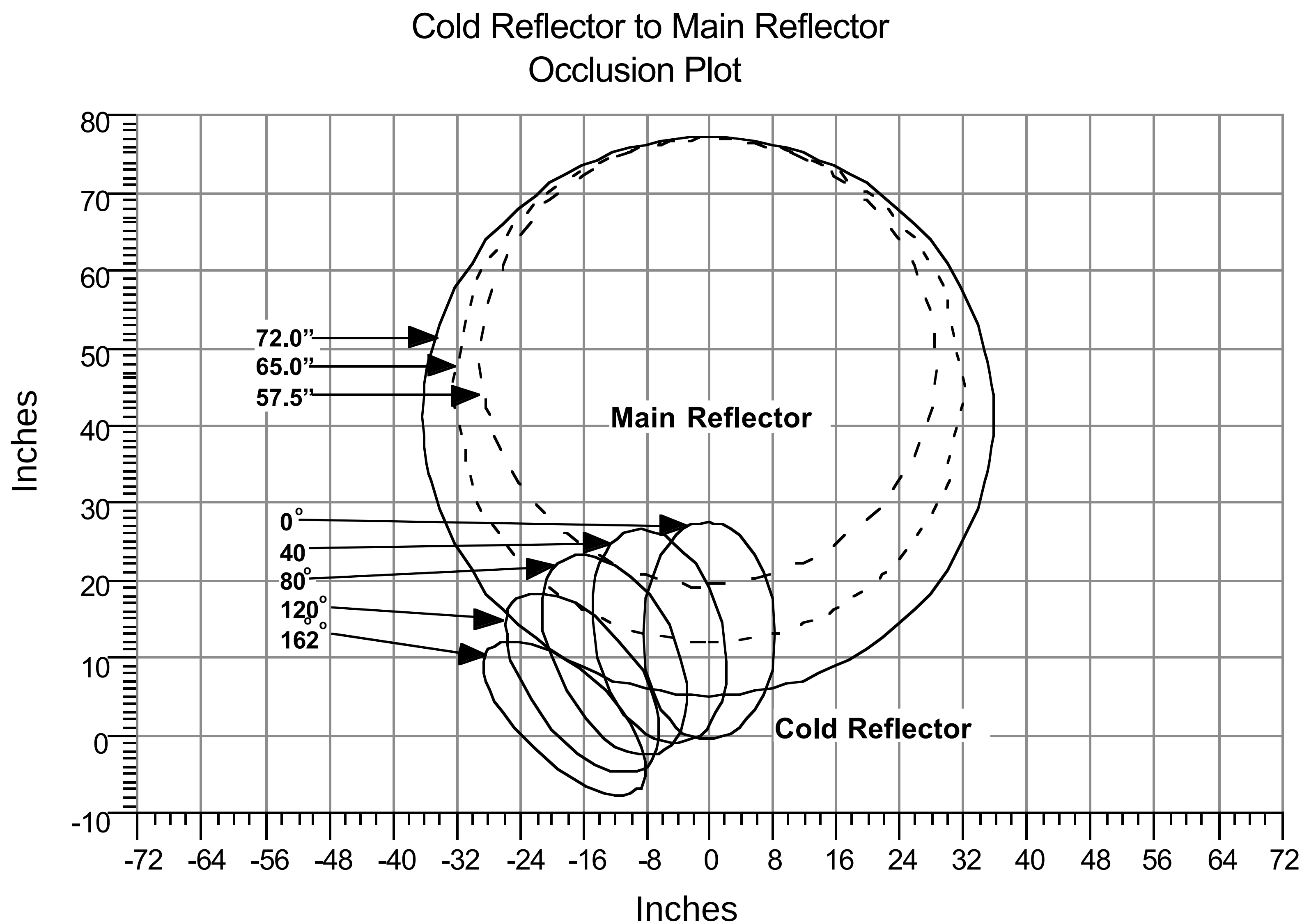
- **Forward Swath 913 Km**
- **Aft Swath 913 Km**



Asymmetrical Cal Case

- **Forward Swath 1053 Km**
- **Aft Swath 769 Km**

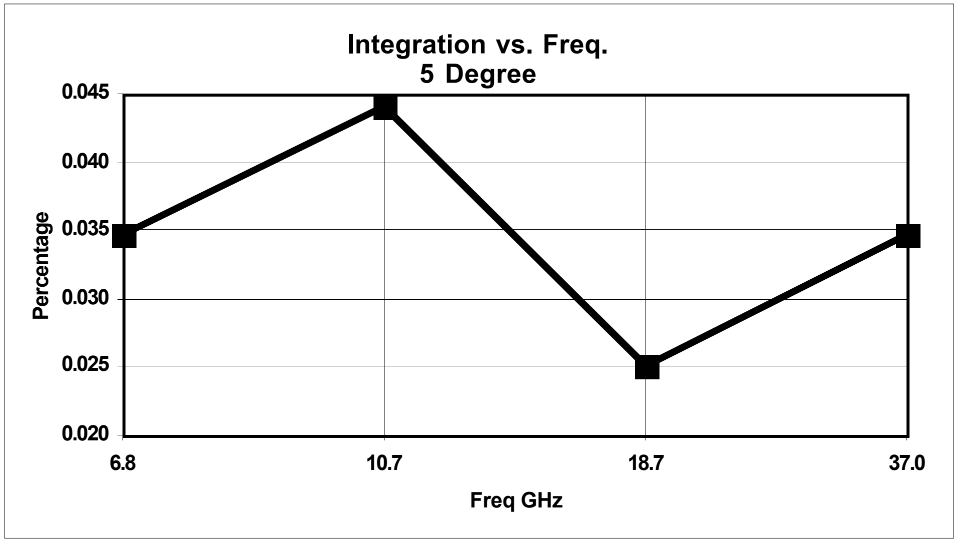
Cold Reflector to Main Reflector Occlusion Plot



Integration of 5 Degree and 20 Degree Parabolic Cold Reflectors

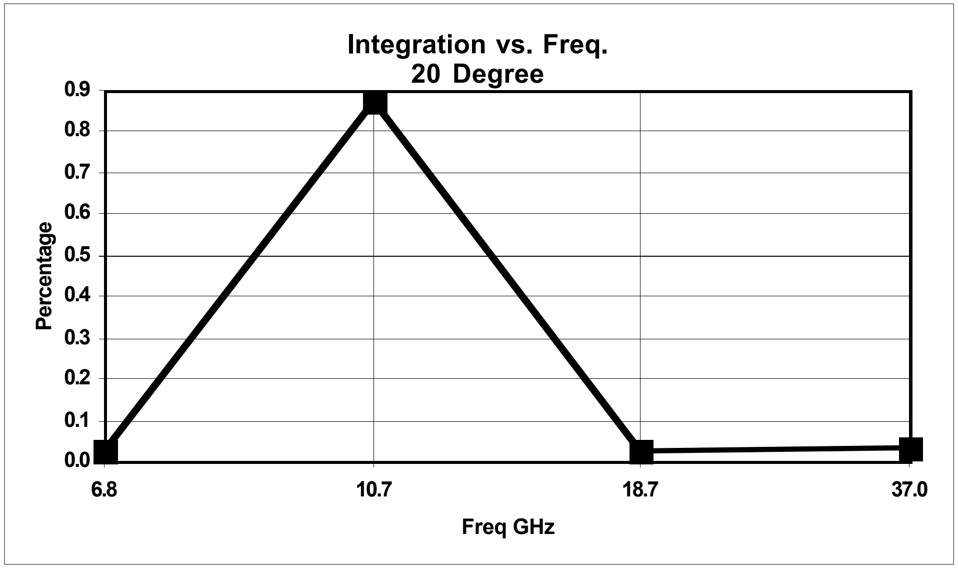
5 Degree

Freq(GHz)	Total	<-27 Deg	Integration	Percentage
6.8	31.37121	0.01086	0.00035	0.03462
10.7	6.60353	0.00291	0.00044	0.04405
18.7	3.69542	0.00093	0.00025	0.02515
37.0	0.35652	0.00012	0.00035	0.03462



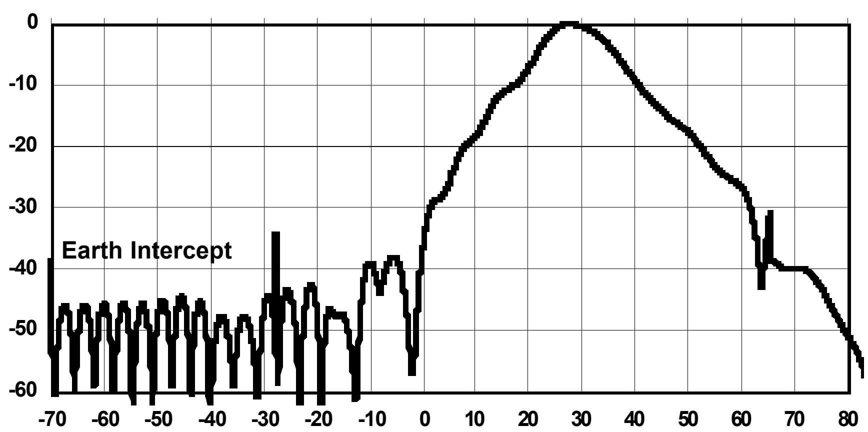
20 Degree

Freq(GHz)	Total	<-27 Deg	Integration	Percentage
6.8	32.17943	0.00820	0.00025	0.02548
10.7	9.33408	0.08131	0.00871	0.87110
18.7	5.87622	0.00144	0.00024	0.02447
37.0	0.56970	0.00017	0.00030	0.02975

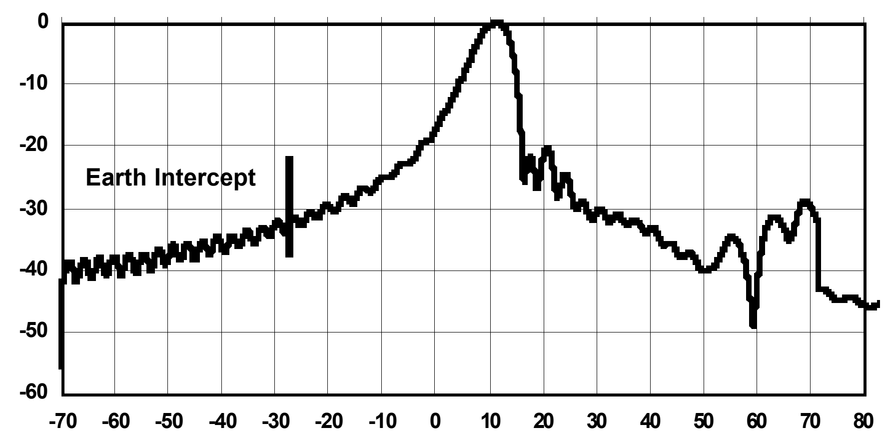


Cold Reflector at 20 Degrees Above the Horizon

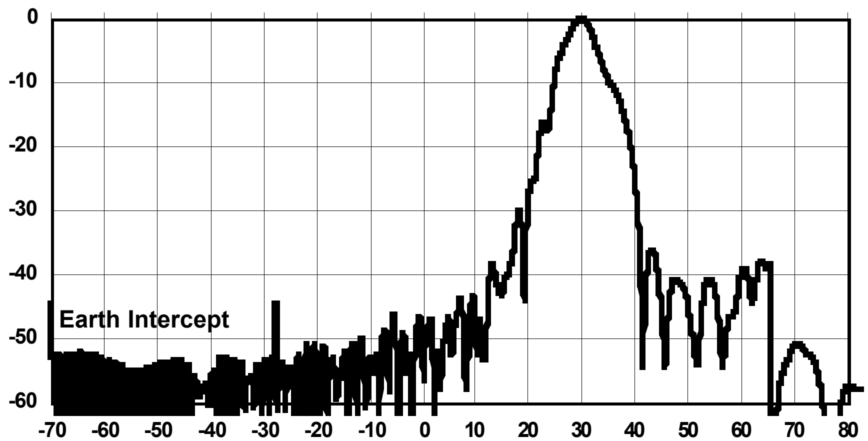
6.8 GHz Cold Reflector



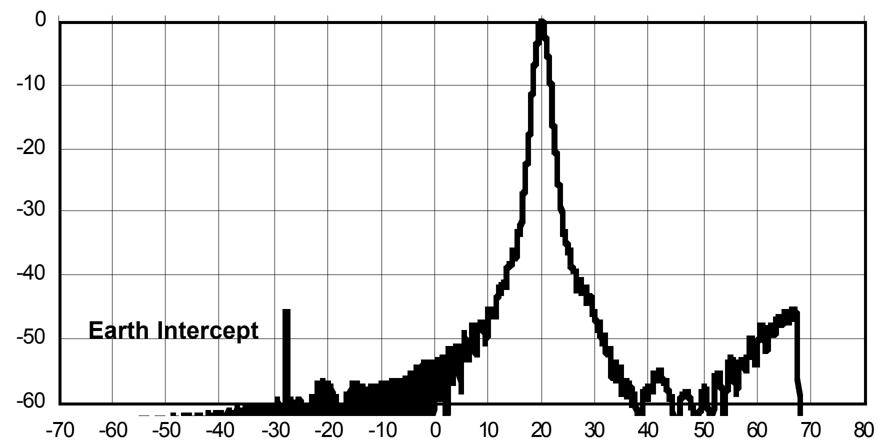
10.7 GHz Cold Reflector



18.7 GHz Cold Reflector

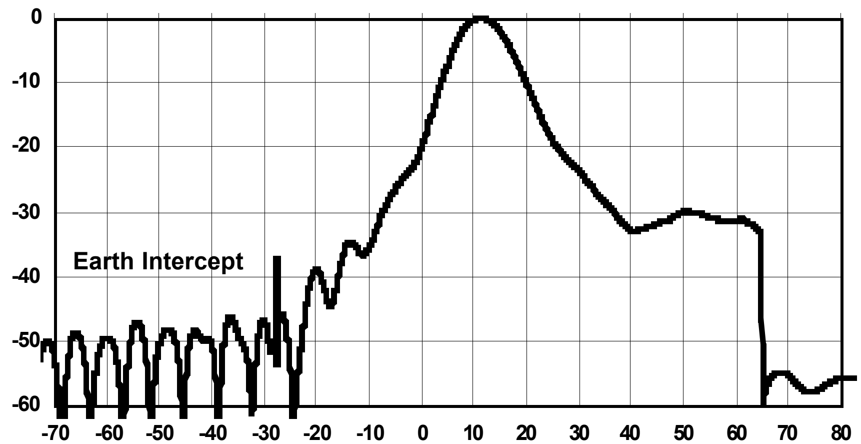


37 GHz Cold Reflector

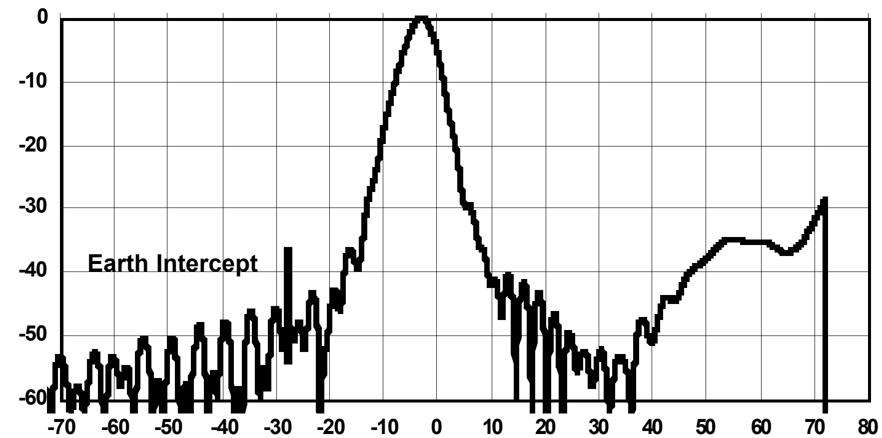


Cold Reflector at 5 Degrees Above the Horizon

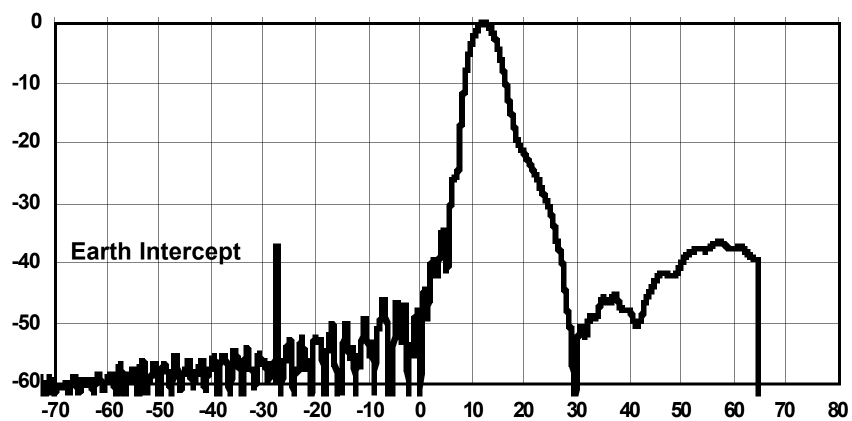
6.8 GHz Cold Reflector



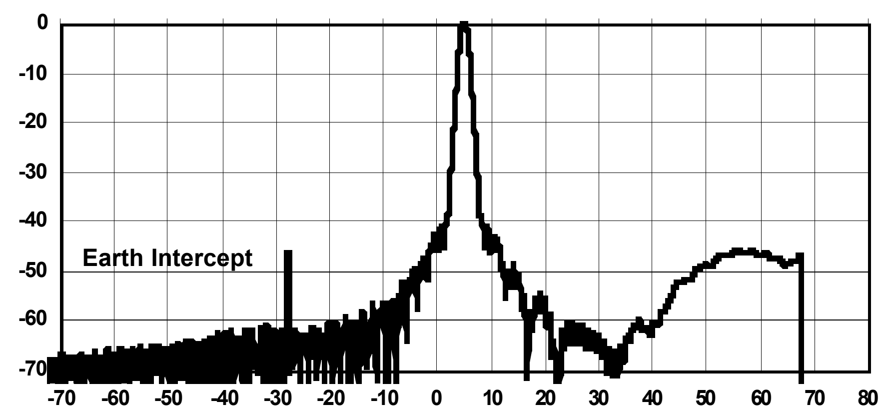
10.7 GHz Cold Reflector



18.7 GHz Cold Reflector

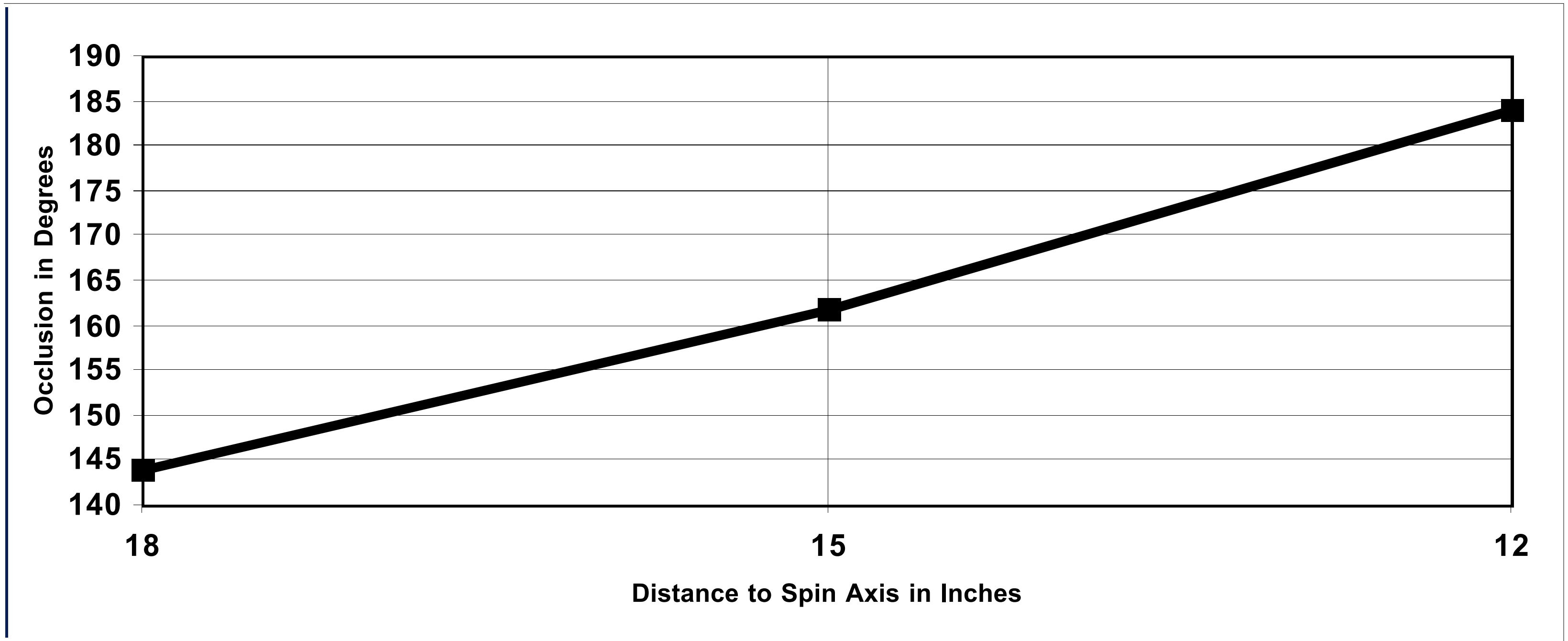


37 GHz Cold Reflector



Cold Reflector Occlusion vs. Spin Axis for 5 Degree Above Horizon

Spin Axis(inches)	Occlusion Angle
18	144
15	162
12	184



Cold Load Implementation Plan

- **Long Lead Items:**
  - **Reflector**
- **Make/Buy Decisions: TBD**
- **Unique Test Equipment Needed**
  - **Antenna Range Measurements for Cold Load Reflector**
- **Vendor Availability: Composite Optics**

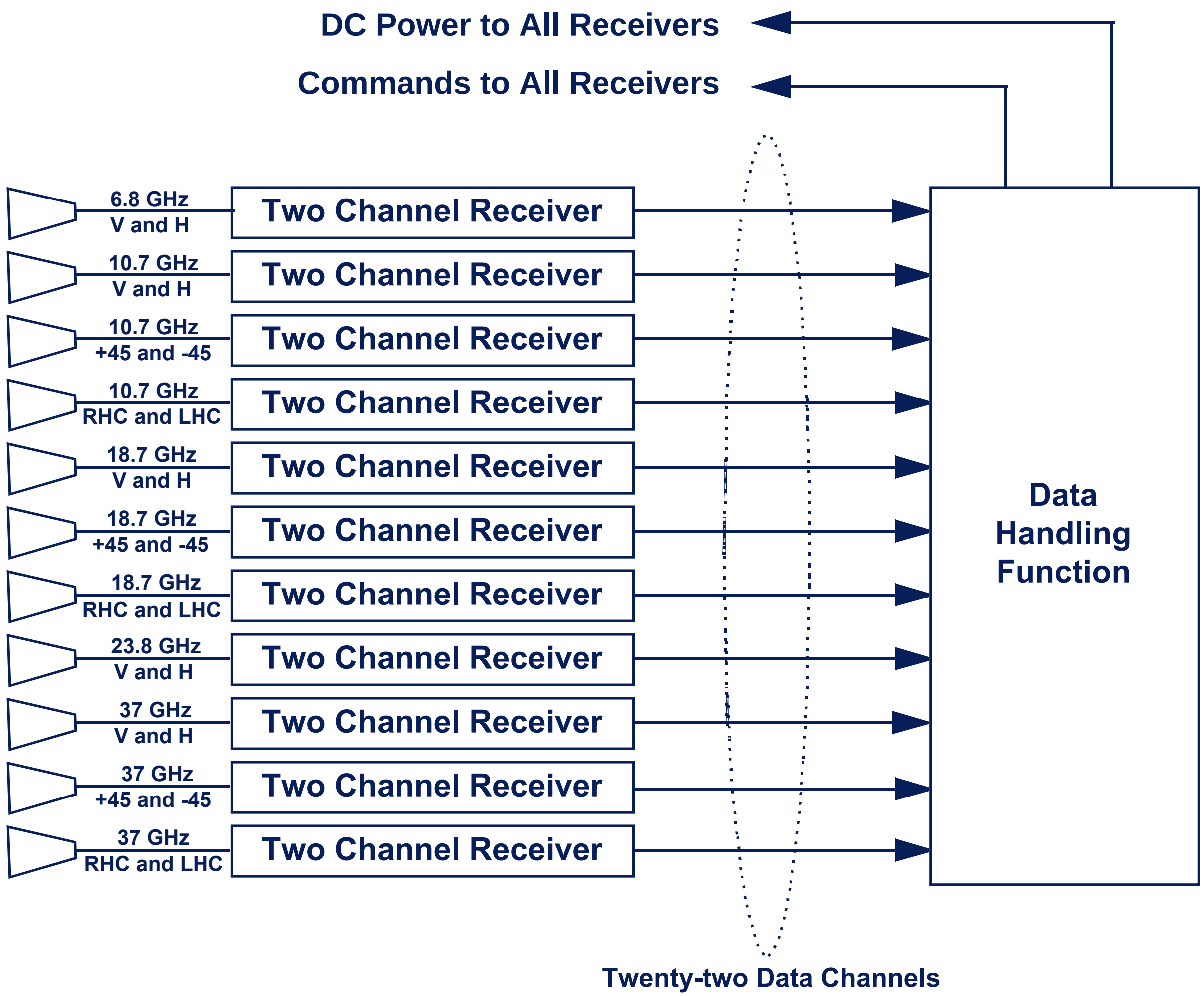
Payload Receiver Subsystem

J. Xavier

Payload Receiver Subsystem
Functional Requirements

- Measure Scene and Calibration Load Temperature for Eleven Polarization Pairs Covering Five Frequency Bands
- Provide Required Radiometric Sensitivity for Each Measurement
- Provide Digital Representation of Scene and Calibration Load Temperatures
- Provide Gain and DC Offset Adjustment Capability

Payload Receiver Subsystem
Top Level Block Diagram



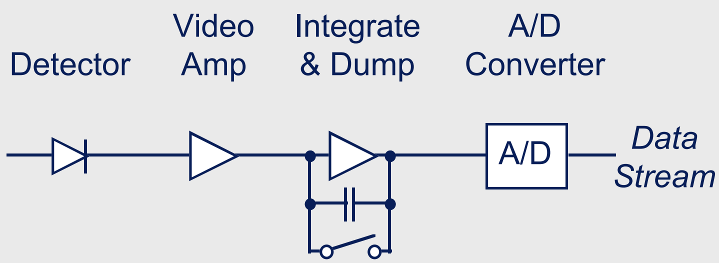
Payload Receiver Subsystem Trade Studies (1 of 3)

- **Detector Type: Schottky vs. Tunnel Diode Detectors**
  - **Tunnel Diodes Have Superior Close-In Noise Performance; Better System Noise Performance With Low Post-Detection Bandwidths**
  - **Tunnel Diodes Have Lower Output Resistance; Allow for Low Resistance Audio Back End, Improved Post-Detection Noise Performance**
  - **Trade Study Complete Tunnel Diodes Preferred Detector Type**
- **Simple Polarization Pair Receiver vs. Polarization Combining Receiver**
  - **Polarization Combining Receiver Reduces Size, Weight, and Power of Receiver Subsystem**
  - **Simple Polarization Pair Receiver Reduces Calibration Complexity, Reduces Cross-Polarization Coupling Paths**
  - **Simple Polarization Pair Receiver Is Current Baseline; Additional Work Evaluating Polarization Combining Schemes to Be Completed Before PDR**

Payload Receiver Subsystem Trade Studies (2 of 3)

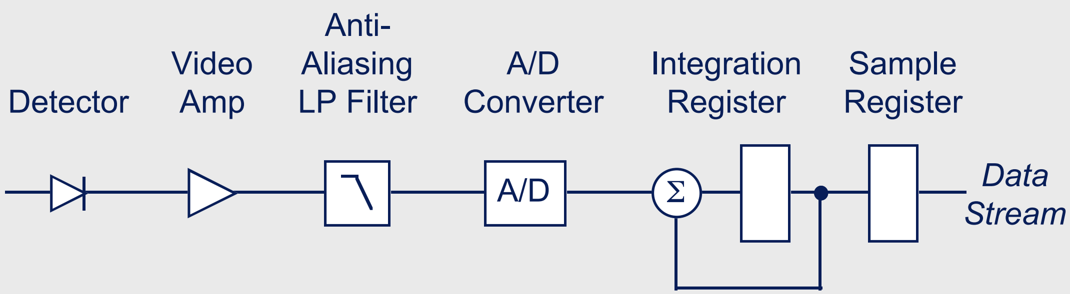
- **Analog vs. Digital Integration**

Analog Integration



- ***Pros***
  - **Potentially Lower Power**
- ***Cons***
  - **Additional Non-Linearities**
  - **Finite Dump Time and Repeatability**

Digital Integration



- ***Pros***
  - **Zero Dump Time and Total Repeatability**
- ***Cons***
  - **Higher Rate A/D**
  - **Possibly Higher Power**

Payload Receiver Subsystem Trade Studies (3 of 3)

- **Front-end RFI Filtering: Size, Weight, and Loss vs. Sensor Availability**
  - **RFI Sources Can Present Large Signals Which Interfere With Sensor**
  - **Preliminary Studies Show That Sensor Availability Should Be High Over Open Oceans**
  - **Studies Continuing to Determine Sensor Availability and Effectiveness in Other Regions**
  - **Study Will Be Complete by PDR**

Payload Receiver Subsystem Allocated Requirements Summary (1 of 2)

Requirement Description	Required Performance	Predicted Performance	Margin
Receiver NEDT at 250 °K			
6.8 GHz	.568 °K	.405 °K	.163 °K
10.7 GHz	.425 °K	.385 °K	.040 °K
18.7 GHz	.425 °K	.416 °K	.009 °K
23.8 GHz	.568 °K	.468 °K	.100 °K
37 GHz	.400 °K	.343 °K	.057 °K
Frequency Channels	6.8 GHz	6.8 GHz	N/A
	10.7 GHz	10.7 GHz	N/A
	18.7 GHz	18.7 GHz	N/A
	23.8 GHz	23.8 GHz	N/A
	37 GHz	37.0 GHz	N/A
Channel Bandwidth			
6.8 GHz	125 MHz	125 MHz	N/A
10.7 GHz	200 MHz	200 MHz	N/A
18.7 GHz	500 MHz	500 MHz	N/A
23.8 GHz	500 MHz	500 MHz	N/A
37 GHz	2000 MHz	2000 MHz	N/A
Receiver Integration Time			
6.8 GHz	5.00 msec	Compliant	N/A
10.7 GHz	3.46 msec		
18.7 GHz	1.98 msec		
23.8 GHz	1.56 msec		
37 GHz	1.00 msec		

Payload Receiver Subsystem
Allocated Requirements Summary (2 of 2)

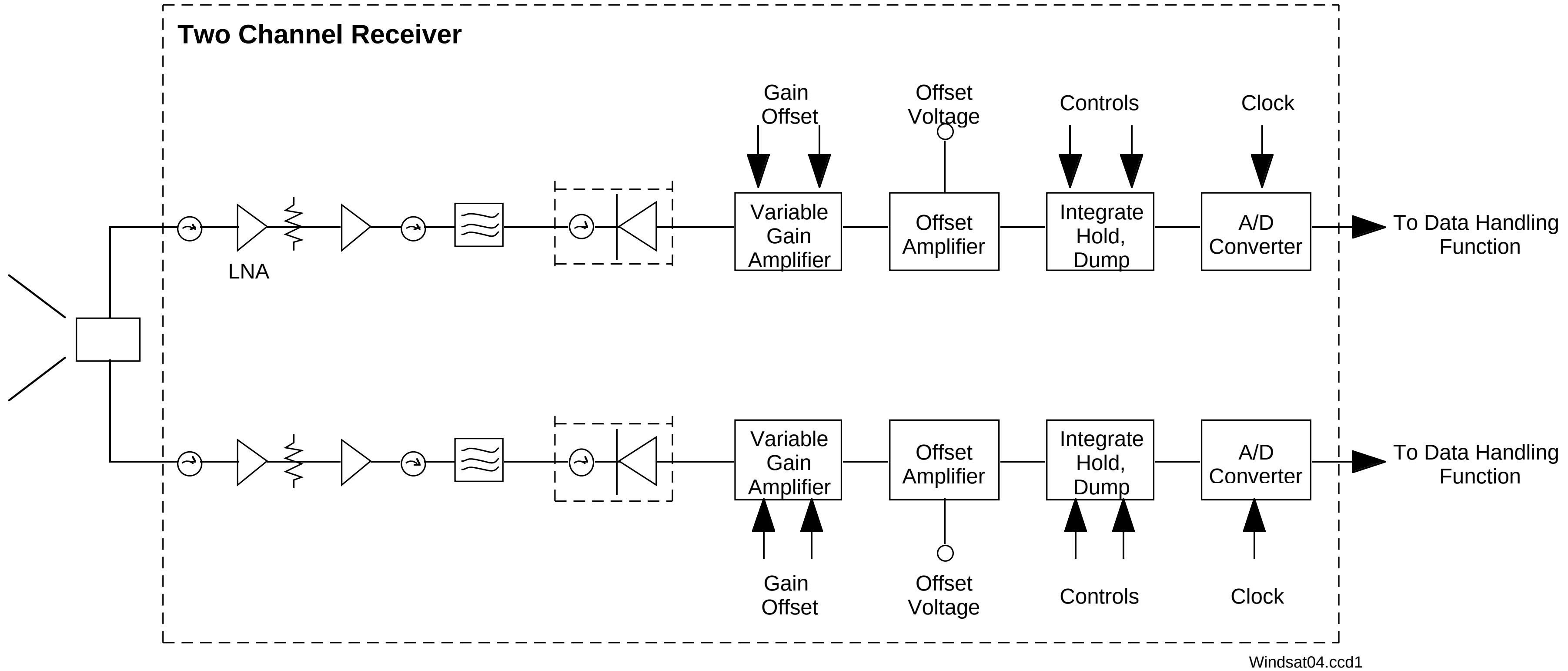
Requirement Description	Required Performance	Predicted Performance	Margin
Input Signal Levels Operating Hot Calibration Non-Destructive	 3 °K to 250 °K 330 °K, Maximum +10 dBm	 N/A N/A +15 dBm	 N/A N/A 5 dB
Cross-Polarization Isolation	55 dB, Minimum	65 dB	10 dB
Bias (Fixed) Measurement Error	.5 °K in Any Receiver Channel	.493 °K at 37 GHz	1.4%

Payload Receiver Requirements
Derived Requirements Summary

Requirement Description	NEDT	Required Performance	Predicted Performance	Margin
Noise Figure 6.8 GHz 10.7 GHz 18.7 GHz 23.8 GHz 37 GHz		 0.90 dB 0.90 dB 1.90 dB 1.90 dB 2.50 dB	 0.82 dB 0.87 dB 1.79 dB 1.79 dB 2.39 dB	 0.08 dB 0.03 dB 0.11 dB 0.11 dB 0.11 dB
Quantization		14 Effective Bits LSB Weighting < .02 °K	14 Effective Bits LSB Weighting < .018 °K	N/A
Channel Data Rate 6.8 GHz 10.7 GHz 18.7 GHz 23.8 GHz 37 GHz		 2.57 kbps 4.04 kbps 7.07 kbps 9.0 kbps 14.0 kbps	 Compliant	 N/A
VSWR		1.2:1, Maximum	1.12	

Payload Receiver Subsystem Design Concept (1 of 3)

- **Two Channel Receiver Detailed Block Diagram**



Payload Receiver Subsystem Design Concept (3 of 3)

NEDT Summary								
Channel	#	1	2	3	4	5		
Center Frequency	GHz	6.8	10.7	18.7	23.8	37	**Notes**	
Max Antenna Temperature	deg K	250	250	250	250	250		
Min Antenna Temperature	deg K	3	3	3	3	3		
Noise Figure	dB	0.82	0.87	1.79	1.79	2.39	Does not include Feedhorn Loss	
Integration Time	ms	5.00	3.46	1.98	1.56	1.00		
Pre-Detection Bandwidth	MHz	125	200	500	500	2000		
Delta T Receiver Front-end	deg. K	0.392	0.378	0.400	0.451	0.327	To in deg K=	290
Video Noise	deg K	0.030	0.030	0.030	0.030	0.030	-20 dBc Noise Contribution	
Delta T Video vs. Temp	deg. K	0.004	0.004	0.005	0.005	0.006		
Delta T ADC Non-Linearities	deg K	0.008	0.008	0.008	0.008	0.008		
Quantization Noise	deg K	0.008	0.008	0.008	0.008	0.008		
Cal Period Delta T (Delta G)	deg K	0.049	0.047	0.053	0.053	0.054		
Delta T (Delta Audio G)	deg K	0.002	0.003	0.004	0.004	0.005	RPM=	29.57
Receiver NEDT	deg K	0.397	0.382	0.405	0.455	0.334	PERIOD (sec)	2.03
Required Receiver NEDeltaT	deg K	0.568	0.425	0.425	0.568	0.400		
Margin	deg K	0.171	0.043	0.020	0.113	0.066		
Receiver Bias Errors								
Long Term Delta T (Delta G)	deg K	0.015	0.015	0.015	0.015	0.015	Combination of RFE AGC and Ground Cal	
Delta T Digital	deg K	0.015	0.015	0.015	0.015	0.015	Quantization Resolution	
Delta T Video vs. Linear	deg. K	0.310	0.314	0.398	0.398	0.463		
Total of Bias Terms	deg. K	0.340	0.344	0.429	0.429	0.493		

Payload Receiver Subsystem
NEDT Effects Due to Detector

NEDT Summary

Channel	#	1	2	3	4	5	
Center Frequency	GHz	6.8	10.7	18.7	23.8	37	**Notes**
Detector Sensitivity	mv/milliwatt	900	800	400	400	300	Tamax in deg K= 250
Min Detector Input Level	dBm	-32.63	-33.32	-32.81	-32.81	-32.24	Tamin in deg K= 3
Max Detector Input Level	dBm	-25.72	-26.62	-28.61	-28.61	-28.93	
Sensitivity Temp Variation	dB/deg C	0.006	0.006	0.006	0.006	0.006	±0.5 dB over -55 to +125 oC
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	
Delta K/K (temperature)	unitless	0.00001	0.00001	0.00001	0.00001	0.00001	
Video Noise	deg K	0.030	0.030	0.030	0.030	0.030	-20 dBc Noise Contribution
Delta T Video vs. Temp	deg. K	0.004	0.004	0.005	0.005	0.006	

Bias Errors

Sensitivity Dev from Linear	%	0.10	0.10	0.10	0.10	0.10	5% is industry standard
Sensitivity Dev from Linear	dB	0.00434	0.00434	0.00434	0.00434	0.00434	2% is industry pain point
Delta K/K (nonlinearity)	unitless	0.00100	0.00100	0.00100	0.00100	0.00100	.1% requires in-house testing
Delta T Video vs. Linear	deg. K	0.310	0.314	0.398	0.398	0.463	

- **2% Deviation From Linearity Over 30 dB Dynamic Range (-50 to -20 dBm)**
- **Temperature Sensitivity Is Manufacturer Specification**
- **Currently Investigating High Precision Linearity Measurements for Characterizing Detectors Over WindSat Actual Dynamic Range**

Payload Receiver Subsystem
NEDT Effects Due to ADC

NEDT Summary

Channel	#	1	2	3	4	5	Notes
Center Frequency	GHz	6.8	10.7	18.7	23.8	37	
Min ADC Input Voltage	V	0.98	1.05	2.35	2.35	4.01	
Max ADC Input Voltage	V	4.82	4.91	6.18	6.18	8.59	
# of raw ADC Bits	bits	16.00	16.00	16.00	16.00	16.00	
Raw ADC Resolution	deg K/count	0.004	0.004	0.004	0.004	0.004	
ADC Non-linearities	LSBs	2.00	2.00	2.00	2.00	2.00	Manufacturer Specification
Delta T ADC Non-Linearities	deg K	0.008	0.008	0.008	0.008	0.008	
# of effective ADC bits	bits	14.00	14.00	14.00	14.00	14.00	
Effective A/D Resolution	deg K/count	0.015	0.015	0.015	0.015	0.015	
Video Offset	A/D counts	-8192	-8192	-8192	-8192	-8192	
Quantization Noise	deg K	0.008	0.008	0.008	0.008	0.008	

Bias Errors

Delta T Digital	deg K	0.015	0.015	0.015	0.015	0.015	Quantization Resolution

- **14 MSBs of a 16 Bit Device Used to Represent the Temperature Measurements**
- **Quantization Noise Based on 14 Bits**
- **-35 dB Between Stokes Parameters Required to Support Phenomenology; This Equates to a Voltage Ratio of 1.00016, or Approximately 1 Part in 6000**
- **14 Bits Provides Twice the Required Resolution**

Payload Receiver Subsystem
NEDT Effects Due to Gain

NEDT Summary

Channel	#	1	2	3	4	5	
Center Frequency	GHz	6.8	10.7	18.7	23.8	37	**Notes**
RF Gain	dB	67.0	64.0	57.0	57.0	50.0	ALL RF Circuitry up to Detector
Gain Variation	+/- dB	2.4	2.4	2.4	2.4	2.4	Manufacturer Specification
Gain vs Temp	dB/deg C	0.067	0.064	0.057	0.057	0.050	Gain Var .015 dB/^{o}
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	Gain 15dB/stage
Delta G	unitless	0.00016	0.00015	0.00013	0.00013	0.00012	
Cal Period Delta T (Delta G)	deg K	0.049	0.047	0.053	0.053	0.054	
Audio Gain	dB	66.0	69.0	81.0	81.0	87.0	per stage EOL = .4% (.04dB)
Min Detector Output Level	mV	0.5	0.4	0.2	0.2	0.2	for 3 year mission
Max Detector Output Level	mV	2.4	1.7	0.6	0.6	0.4	Temp Variation 300ppm/ C/stage
Gain vs Temp	dB/deg C	0.0069	0.0072	0.0084	0.0084	0.0090	Equiv = .0026 dB/^{o}
Temp. Drift	deg C/sec	0.005	0.005	0.005	0.005	0.005	Audio Gain 25 dB/stage
Delta G (temperature)	unitless	0.000008	0.000008	0.000010	0.000010	0.000011	
Delta T (Delta G)	deg K	0.002	0.003	0.004	0.004	0.005	RPM= 29.57

Bias Errors

Long Term Delta T (Delta G)	deg K	0.015	0.015	0.015	0.015	0.015	Combination of RFE AGC and Ground Cal

- **RF Gain vs. Temperature From Industry App Note for FET Amps Without Temperature Compensation**
- **Total Gain Variation Based on Manufacturer Specs for Typical Amplifiers; This Determines Gain Control Requirements**
- **Audio Gain vs. Temperature Assumes Op-Amp Type Circuit With Sufficient Open-Loop Gain So That Feedback Elements Determine Gain Variation**

Payload Receiver Subsystem Implementation Plan

- Waveguide Isolators and Waveguide Input to LNAs
- Coaxial Interfaces From LNA Output Through Audio Circuitry Input
- Audio Circuitry/Data Conversion Housed in Custom Chassis, 1 Polarization Pair Per Chassis
- LNAs Have 22 Week Delivery
- Filters Are Semi-Custom; Have 20 Week Delivery
- “Flight-Like” Breadboard of 10.7 and 37 GHz Receivers

Payload Receiver Subsystem
Test Equipment

- Detector Characterization Requires 6.8-37 GHz Power Combiners
- System Test Requires Hot/Cold Source
- CW Testing Requires 6.8 - 37 GHz Signal Sources HP83651B (2)
- HP8510C Network Analysis System
- HP8566B Spectrum Analyzer With External Q-Band Mixer/Amp
  - Mixer, HP11974Q
  - Mixer, HP11970K
  - Amplifier, HP11975A
- Noise Figure Test Set With ENR Source Covering 6.8 - 37 GHz
- High Resolution Volt Meter

Payload Data Handling Subsystem

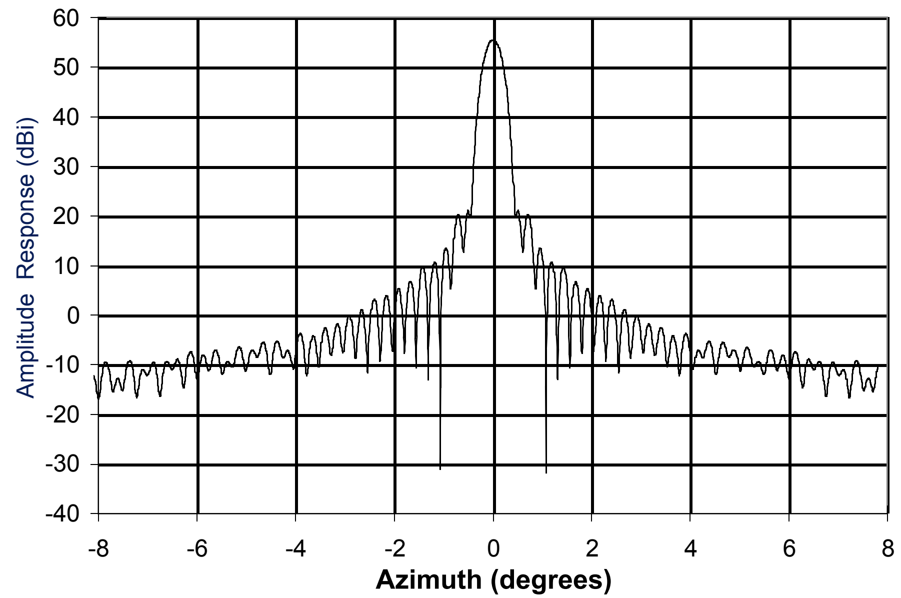
Stuart Nicholson

Payload Data Handling Subsystem Requirements

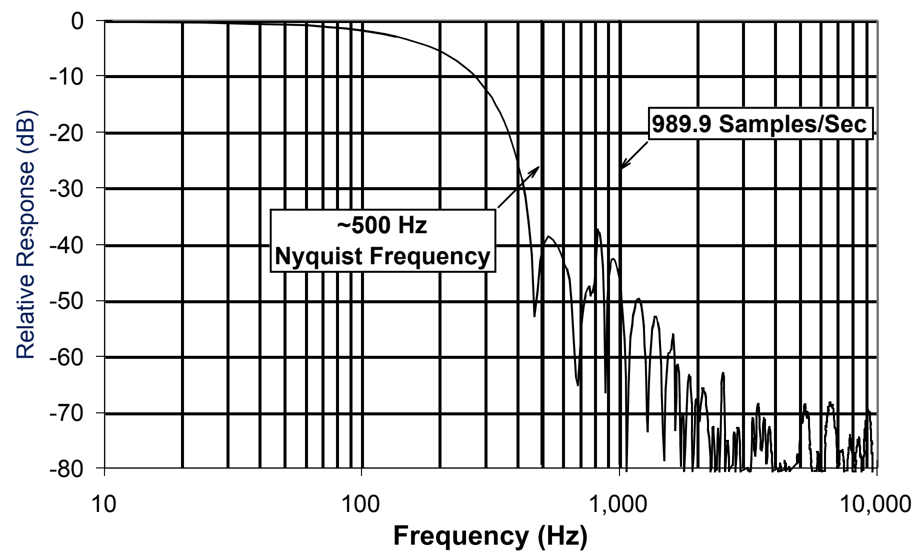
- Generate Integrator Sampling and Synchronization Control Signals
  - At or Above the Spatial Nyquist Rate of the Scanning Antenna
  - Synchronized With Antenna Rotation to Maximize Calibration Repeatability
- Associate Attitude, Position, Integrator Timing, and Scan Angle with UTC Timescale to 10 us Accuracy
  - Derived from Position Determination Allocation to SAA Spin Control Subsystem of 0.002° [(0.002° / 360°) x (60 secs/min / 29.57 RPM)]
- Output Single Framed Data Stream for All Payload Data Sources
- Calculate and Append Error Detection CRC to Serial Data Frame
- Collect and Report Receiver Physical Temperature Data
- Interface with Slip Rings to Provide:
  - Serial Telemetry Data from Radiometer Payload
  - Serial Command Data to Radiometer Payload
  - Basic Command and Control Interfaces with T&C
  - Timing Reference Accurate to 10 us
- Condition Spin Synchronization Signal from Mechanical Sensor

Integrator Sampling Rate Analysis

- **Antenna Patterns Generated with OSU Reflector Software**
- **37 GHz Band Shown**



- **2 Samples Per 3 dB Beamwidth Baselined**
- **0.02% of Total Power Above Nyquist Frequency**



Sensor Data Rate Analysis

Determination of WindSat Sensor Data Rate

11-Sep-97	Stuart Nicholson
9-Oct-97	Rev 1, Stuart Nicholson/Peter Gaiser
25-Oct-97	Rev 2, Stuart Nicholson
2-Dec-97	Rev 3, Incorporated Peter Gaiser Changes of 14 Nov 97

Assumptions

24 dB Edge Taper
Circular Orbit

Band-Related Parameters

Parameter	*6.8 GHz*	*10.7 GHz*	*18.7 GHz*	*23.8 GHz*	*37 GHz*	*Units*
Frequency	6.8	10.7	18.7	23.8	37	GHz
Num Antennas	1	3	3	1	3	
Num Polarizations	2	2	2	2	2	
Reflector Size	**72**	**72**	**72**	**72**	**72**	Inches
Bits/Sample	14	14	14	14	14	
Samples/Beam	2	2	2	2	2	

SC Parameters

Parameter	*Value*	*Units*
Spin Rate	**29.57**	rpm
Altitude	**850**	km

Misc Parameters

Parameter	*Value*	*Units*
BW multiplier for degrees…	**80.2**	"homers"
Fraction of Swath Sampled	100	%
Earth Radius	3,444	nmi

Computed Characteristics

Parameter	*6.8 GHz*	*10.7 GHz*	*18.7 GHz*	*23.8 GHz*	*37 GHz*	*Units*
Wavelength	1.74	1.10	0.63	0.50	0.32	Inches
3dB Beamwidth	1.93	1.23	0.70	0.55	0.36	Degrees
Time/Beam	0.01089	0.00692	0.00396	0.00311	0.00200	secs
Sample Rate/Chnl	183.6	288.9	504.8	642.5	998.9	S/Sec
Samples/Ch/Spin	372.5	586.1	1,024.4	1,303.7	2,026.8	S/Ch/Spin
Samples/Spin	745.0	3,516.8	6,146.1	2,607.4	12,160.8	S/Spin
Bit Rate/Chnl	2,570	4,044	7,068	8,995	13,984	bps
Bit Rate/Band	5,140	24,265	42,406	17,991	83,905	bps
Mbits/Rev	30.0	141.6	247.4	105.0	489.5	Mb/Rev
Mbits/Day	423.5	1,999.3	3,494.2	1,482.4	6,913.6	Mb/Day

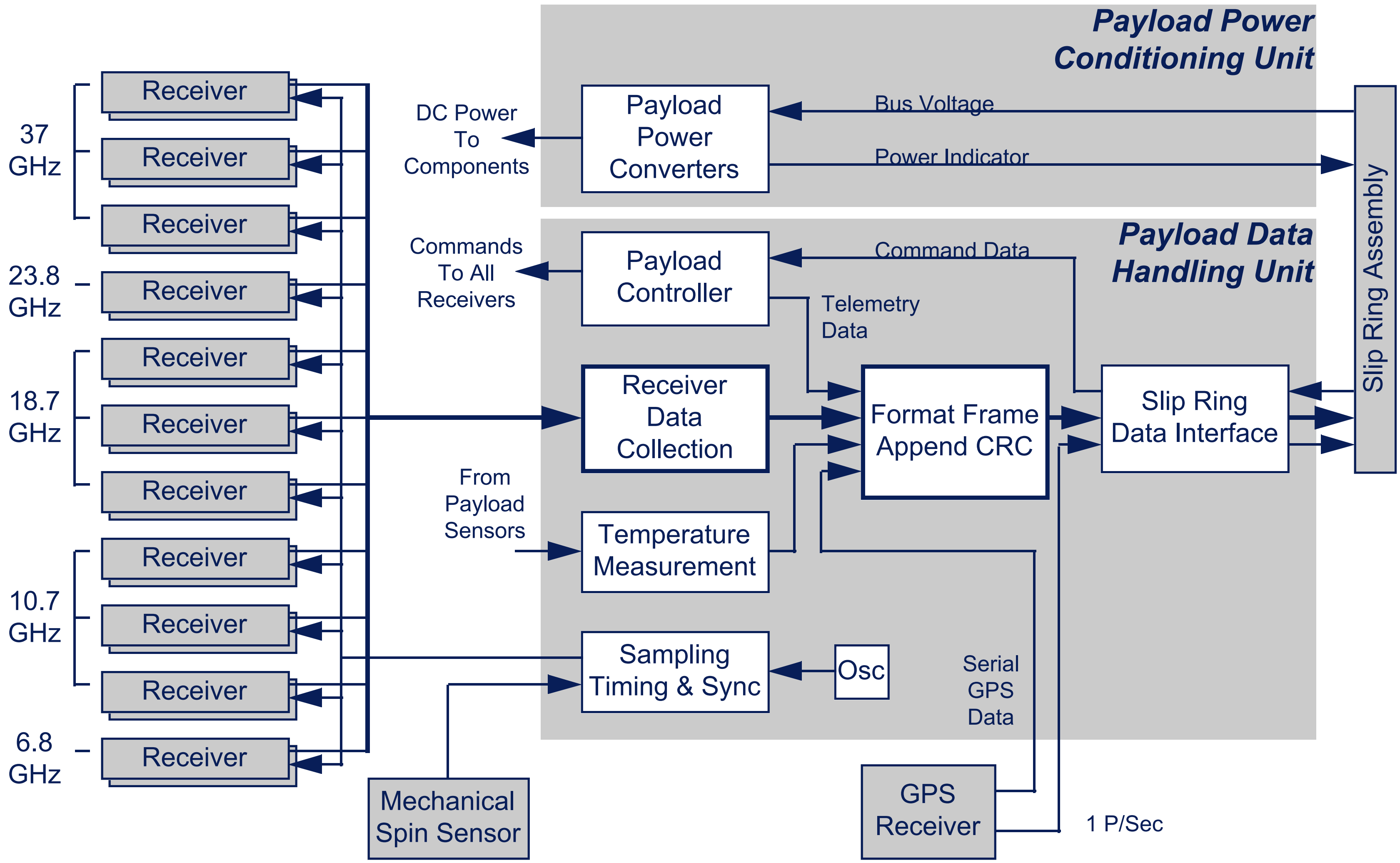
Totals

All Bands	*Units*
25,176.1	**S/Spin**
173,707	**bps**
1,013	**Mb/Rev**
14,313	**Mb/Day**

Computed Parameters/Constants

Parameter	*Value*	*Units*
km/nmi	1.852	
sec/day	86,400	
Period	102	min
Revs Per Day	14.08	

Payload Data Handling Unit
Block Diagram and Interfaces

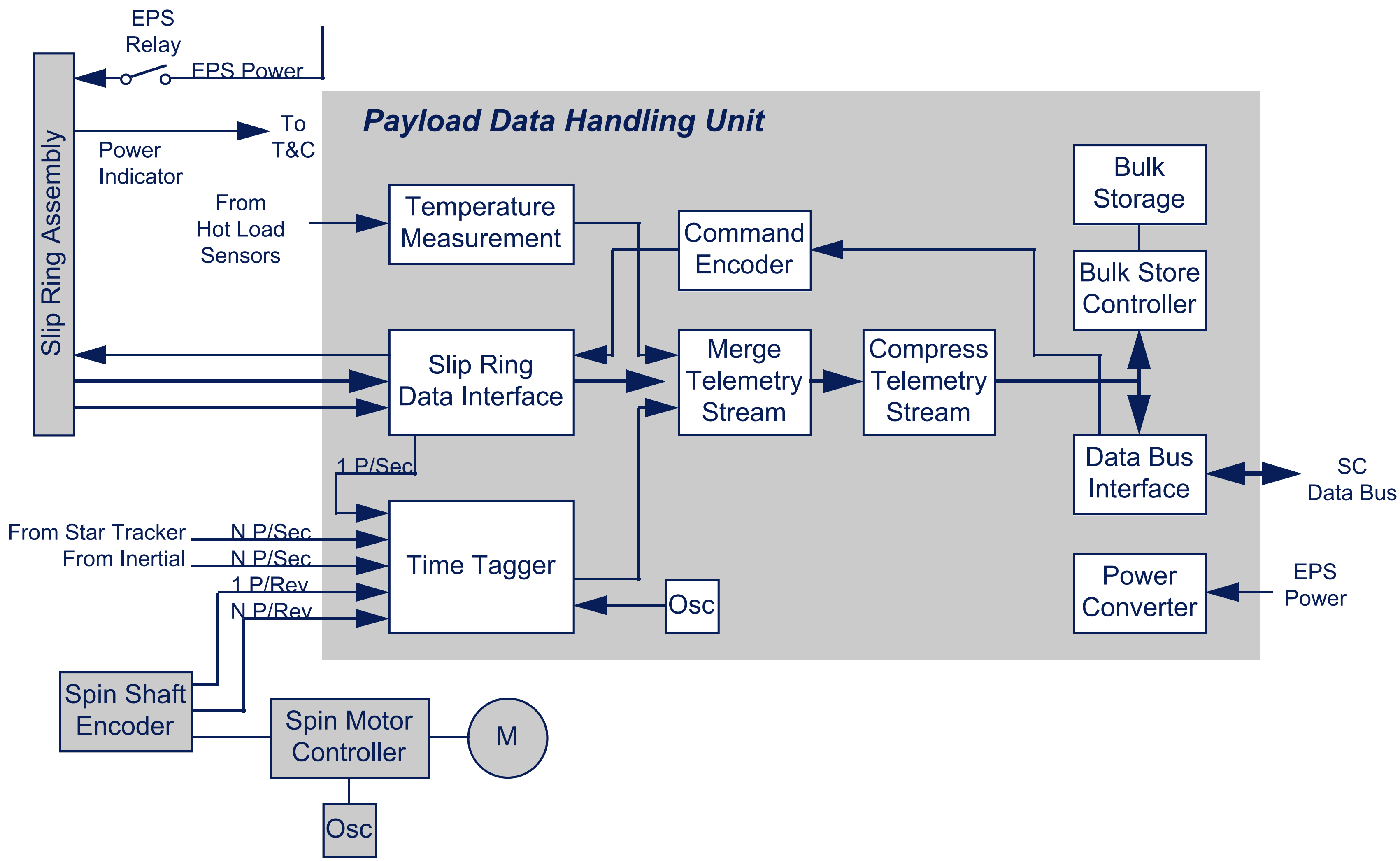


Payload Data Handling Unit
Sample Frame Format

Start of Spin

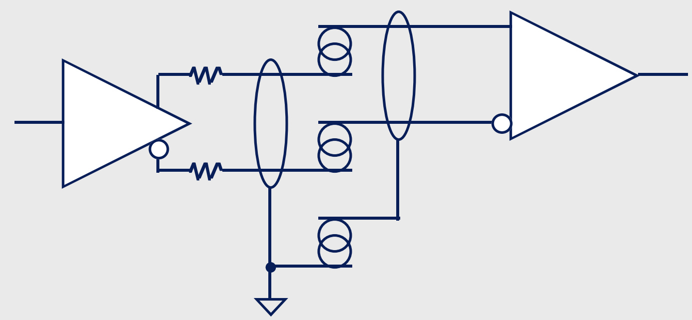
Spin Count	GPS Data	Receiver Telemetry	Temperature Data	Cold Calibration Data	Fore Scene Data
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Fore Scene Data				
GPS Data	Temperature Data	Hot Calibration Data	Aft Scene Data		
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data				
GPS Data	Aft Scene Data	Frame CRC			

Payload Data Handling Unit
Block Diagram and Interfaces

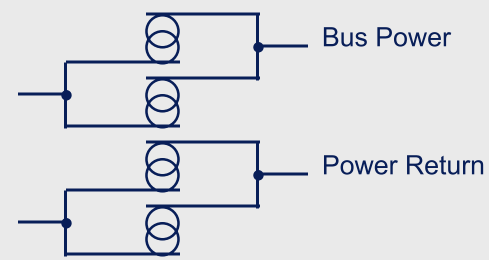


Payload Data Handling Unit
Slip Ring Electrical Interface Details

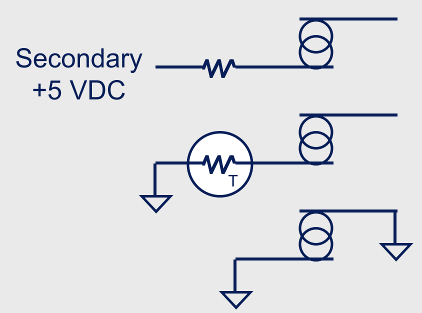
- *Data & GPS 1 P/Sec Interface*
  - Differential, Source-Terminated
  - Dedicated Shield
  - Self-Clocking NRZ
  - Fully Redundant
  - Bandwidth, Resistance Specs



- *Power Interface*
  - Redundant Rings
  - Parallel Connection
  - Return Isolated from Structure



- *T&C Interface*
  - Power-Applied Indicator
  - Temperature Monitor
  - Signal Ground Reference
  - Fully Redundant



WindSat Telemetry List (Preliminary)

- **Radiometer Data**
  - **Fore and Aft Scene Data** — **133,754 bps**
  - **Hot and Cold Load Data** — **39,953 bps**
  - **Hot Load Temperature** — **768 bps**
- **Position and Attitude Support Data**
  - **GPS Position and Time** — **2,182 bps**
  - **Star Tracker** — **2,560 bps**
  - **IMU Attitude** — **5,440 bps**
  - **Spin Clock Angle** — **5,077 bps**
- **Health and Status Data**
  - **Low Precision Temperature** — **80 bps**
  - **Electrical Power Subsystem** — **320 bps**
  - **General Configuration and Status** — **253 bps**
- **Overhead (Framing, CRC)** — **3,216 bps**

- **TOTAL** — **193,603 bps**

Communications Subsystem

P. Lyon

Allocated Requirements

- **Facilities**
  - **Compatible With a Number of C^3 Elements Including NOAA CDAs, EUMETSAT CDAs and AFSCN RTSs**
  - **Compatible With Minimal Impact on Field Terminals Such as AN/UMQ-13 Mark IVB, AN/TMQ-43 (STT), SMQ-11, AN/UMK-3 (TESS), AN/TMQ-44, and Appropriate Civilian Terminals**

Derived Requirements (1 of 2)

- Data Rates
  - Command Uplink Rate Equal to or Less Than TBD Kbps
  - Housekeeping Downlink Data Rate Equal to or Less Than TBD Kbps
  - Payload Downlink Data Rate Equal to or Less Than TBD Mbps
  - Tactical Downlink Data Rate Equal to or Less Than 200 Kbps
- Communication Coverage
  - Command Uplink Greater Than TBD Percent of Radiation Sphere
  - Housekeeping Downlink Greater Than TBD Percent of Radiation Sphere
  - Payload Downlink Earth Coverage With Normal Satellite Attitude
  - Tactical Downlink Earth Coverage With Normal Satellite Attitude
  - Tactical Downlink to SMQ-11 At 200 Kbps (174 Kbps + 15% Overhead)

Angle Off Nadir (Deg)	Minimum EIRP (dBm)
0 to 26	25.1
26 to 42	27.2
42 to 56	30.9
56 to 60	33.5
60 to 62	35.0

Derived Requirements (2 of 2)

- **Ephemeris Knowledge**
  - **Satellite X, Y, Z Position to Less Than 150 Meters, One Sigma (Payload Requirement)**
- **Subsystem Reliability**
  - **TBD**

Trade Studies to Arrive at Recommended Conceptual Design

- AFSCN/SGLS vs NASA/STDN vs Other (TBD) Type Communications
  - (SGLS Operates 1.76 to 1.84 GHz Uplink and 2.2 to 2.3 GHz Downlink
    STDN Operates 2.03 to 2.14 GHz Uplink and 2.2 to 2.3 GHz Downlink)
- GPS Receiver vs Coherent Ranging for Spacecraft Position Determination
- Antenna Types for Uplink and Downlink (Related to First Listed Trade)
- Antenna Location Studies (Bus Dependent)

On Board Bulk Storage

Bert Plourde

On-Board Storage Requirements

- Raw Data Input Rate 194 Kbit/sec
- Output Rate Consistent With System Architecture
  - Downlink Rate Capability of Ground Station Is The Driver
    - Example 2.66 Mbs for Enhanced AFSCN Sites
- Storage Capacity Consistent With System Architecture
  - Number, Location, and Downlink Rate Capability of Ground Station is the Driver
- Meet WindSat Environmental Requirements

Payload Data Rate

Source	Rate	Per Orbit
Sensor Rate	174 kbit/sec	1.05 Gbit/Orbit
Telemetry	20 kbit/sec	0.121 Gbit/Orbit
Total Raw Data Rate	194 kbit/sec	1.2 Gbit/Orbit

Rates Without Data Compression

Solid State Recorder Trades

- **Required Storage Capacity Depends on Number And Location of Ground Stations**

  - **Studies Indicate 5 to 10 GHz May Be Required**

- **Once Storage Capacity Is Determined, Then There Will Be a Trade Between Vendors on Basis of Size, Weight, Power, Cost, And Availability**

Example Solid State Recorder Solution

- COTS Alternatives Under Consideration: SEAKR, TRW, Odetics, Other
- Odetics SSR 6440 Series
  - 13 G Capacity (Expandable to 512 G)
  - Single String or Dual Redundant Available
  - No Single Point Failures
  - Simultaneous Record and Playback
  - Rad-Hard Microcontroller Devices
  - Space Radiation Tolerant 64 Mb DRAMS
  - EDAC
  - 8.5 Lbs, 8 Watts, 11.6” x 9.6” x 4.0”

Current Status and Planned Actions

- **Refine Requirements**
  - **Final Requirements Consistent With Ground Architecture**
- **Perform Initial Vendor Screening**

Electrical Power Subsystem

Baker

Requirements

- **EPS Requirements for Payload and Bus**

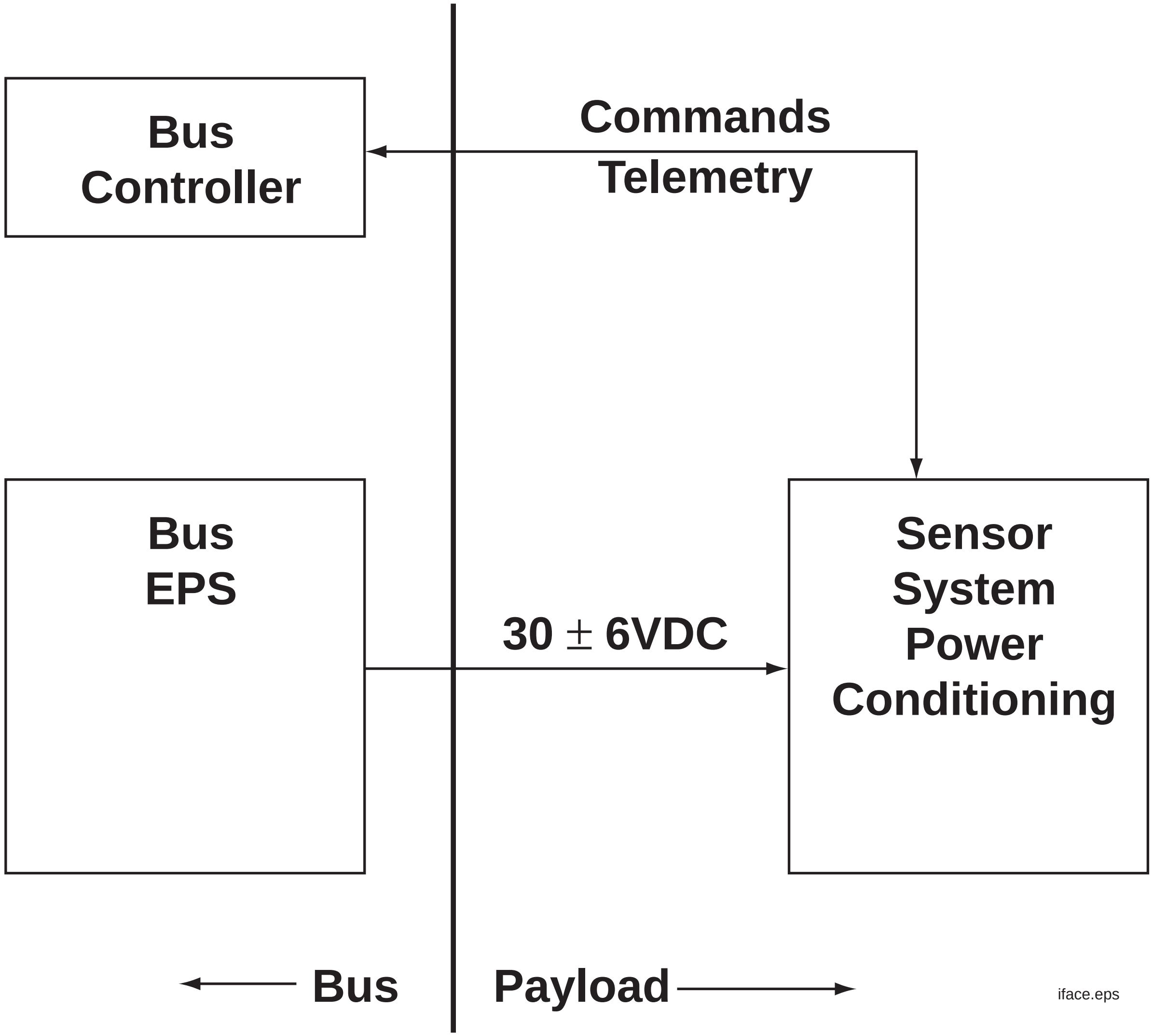
- **Bus EPS Studied in Order to Understand Payload Driven Requirements**

Requirement	Implementation	Allocation
Supply Electrical Power During All Mission Phases	Solar Array, Battery And Power Control And Distribution Electronics	Bus / Payload
Energy Balance On An Orbital Basis	Solar Array Sized To Provide Sufficient Power For Loads And Battery Charge	Bus
Three Year Life	Solar Array Derating, Limited Battery Dod, Battery Temp < 20°C, Parts Selection, Screening And Derating	Bus / Payload
Survivability	System Shall Prevent Fully Discharging The Battery And Shall Isolate Loads Drawing Excess Current	Bus

Derived Requirements

Requirement	Tentative Implementation	Allocation
WindSat Designed for 30±6V	Bus Decision	Bus
Command Precedence	Command Override Shall Be Included for All Autonomous Functions	Bus
EMI/EMC Compatibility	MIL-STD-461C (Tailored)	Bus / Payload
Solar Array Orientation	No Obscuration of Field of View (FOV) of Antenna	Bus

EPS Bus / Payload Interface



Load Power Summary

WINDSAT POWER SUMMARY		
Subsystem	Power	Spun/Despun
Receiver	314 W	Spun
Digital/Power	198 W	Spun
ACS	51 W	Despun
Calibration	0 W	Despun
Structures (incl. Spin Driver)*	21 W	Spun
Thermal Control	75 W	Spun
Payload Total	659 W	Spun & Despun
Spun Total	608 W	
Despun Total	51 W	

* Power Includes Balance Mechanisms and GPS Receiver

- **Power Includes Growth Margin**
- **Power Based Upon 100% Duty Cycle**

Mission Software
Computer Software Configuration Items

R. Gonyea

Flight Software Development (1 of 2)

- On-Board Payload Control Software

- Other On-Board Flight Software

- Command and Control Ground Software

- Mission Data Processing Ground Software

Flight Software Development (2 of 2)

- Requirements Definition
- Flight Software Functions
  - T&C CSCI
  - Data Handling CSCI
- Flight Software Target Systems
  - Flight On-Board Computer
  - Engineering Development Unit
- Flight Software Environment
  - COT Run-Time System: Ada or VxWorks (COTS)
  - COTS Software Tools: Compiler (Ada or C), Debugger, Profiler
- Software Development Plan
  - Formal Development Methodology
- Software Test Plan
  - Formal Test Methodology

On-Board Payload Control Software

- **Payload Control Software**
  - **Payload Engineering Telemetry Data Acquisition**
  - **Payload Command Interpretation and Distribution**
  - **Payload Data Formatting**
  - **Payload Spin Motor Control - TBD Depending on Slip Ring Drive Assembly Selected**

Payload Control Software

- Payload Engineering Telemetry Data Acquisition
  - Data Acquisition Scheduling
  - Telemetry Data Formatting Into Spacecraft Bus Format
- Payload Command Interpretation and Distribution
  - Command Interpretation - Translation From Spacecraft Bus Format to Payload Command Format
  - Command Distribution to Payload Components
- Payload Data Formatting
  - Framing, Time-Tagging, Spin Synchronization, Error Control
- Payload Spin Motor Control
  - TBD Depending on SDA Selected

Other On-Board Flight Software

- **T&C Functions**
  - **TBD Depending on Spacecraft Bus Selected**
- **ACS Functions**
  - **Star Tracker Functions - TBD Depending on Star Tracker Selected**
  - **Attitude Control and Position Determination - TBD Depending on Spacecraft Bus Selected**

Command and Control Ground Software

- **Command Synthesis**
  - **Command Database - Validated Command Suite**
  - **Scripts and Rules**
- **Telemetry Data Processing and Display**
  - **Telemetry Data Decommutation**
  - **Telemetry Database Maintenance**
  - **Telemetry Data Display - Critical Parameter Limits Checking**
  - **Rules Triggering**
- **Interface to Terrestrial C&C Network**
  - **Translation to/from C&C Protocols, Formats**

Mission Data Processing Ground Software

- Mission Data Decommutation
- Mission Data Processing
  - RDR Processing
  - TDR Processing
  - SDR Processing
  - EDR Processing
  - EDR Validation
  - Data Archive
- Mission Data Distribution

Flight Software Development Methodology

- **Requirements Definition**
  - **Software Requirements Derive From:**
    - **Mission Requirements**
    - **Payload Primary and Derived Requirements**
    - **Interface Definitions**
- **Preliminary Design and Requirements Allocation**
- **Detail Design**
- **Code and Unit Test**
- **Integration and Design Validation**
- **Qualification Test**
  - **Traceable to Primary and Derived Requirements, ICDs**

Requirements Map to Key Characteristics

- Processing Timing
  - Response Time Constraints - Processing Timeliness
  - Latency Constraints
- Processing Throughput
  - Control Rates - Peak and Average
  - Process Rates - Peak and Average
  - Data Rates - Peak and Average
  - Event Rates - Peak and Average
- Memory Size
  - Buffer Size
  - Code Size
- I/O Rates

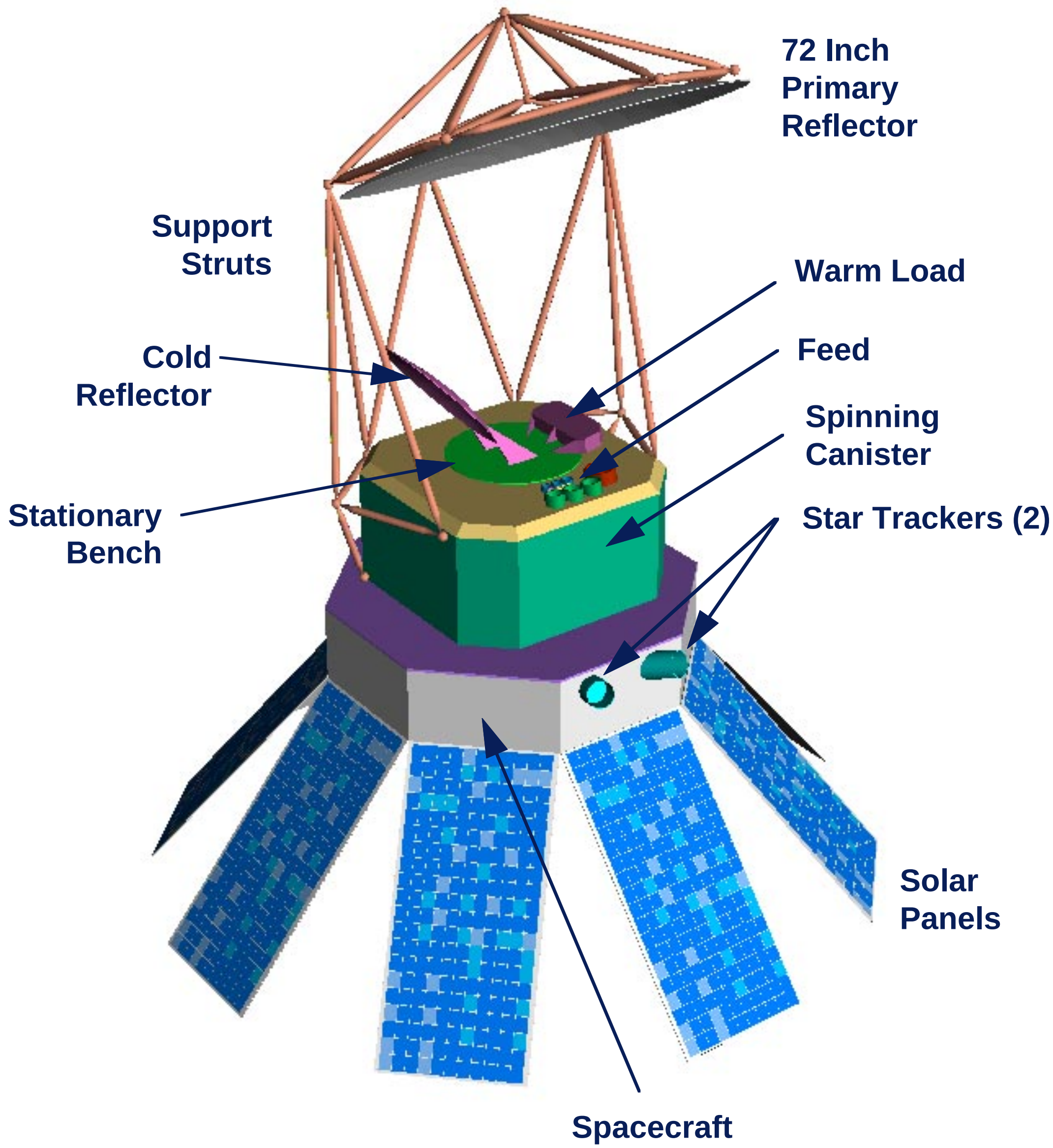
Payload Mechanical

Purdy

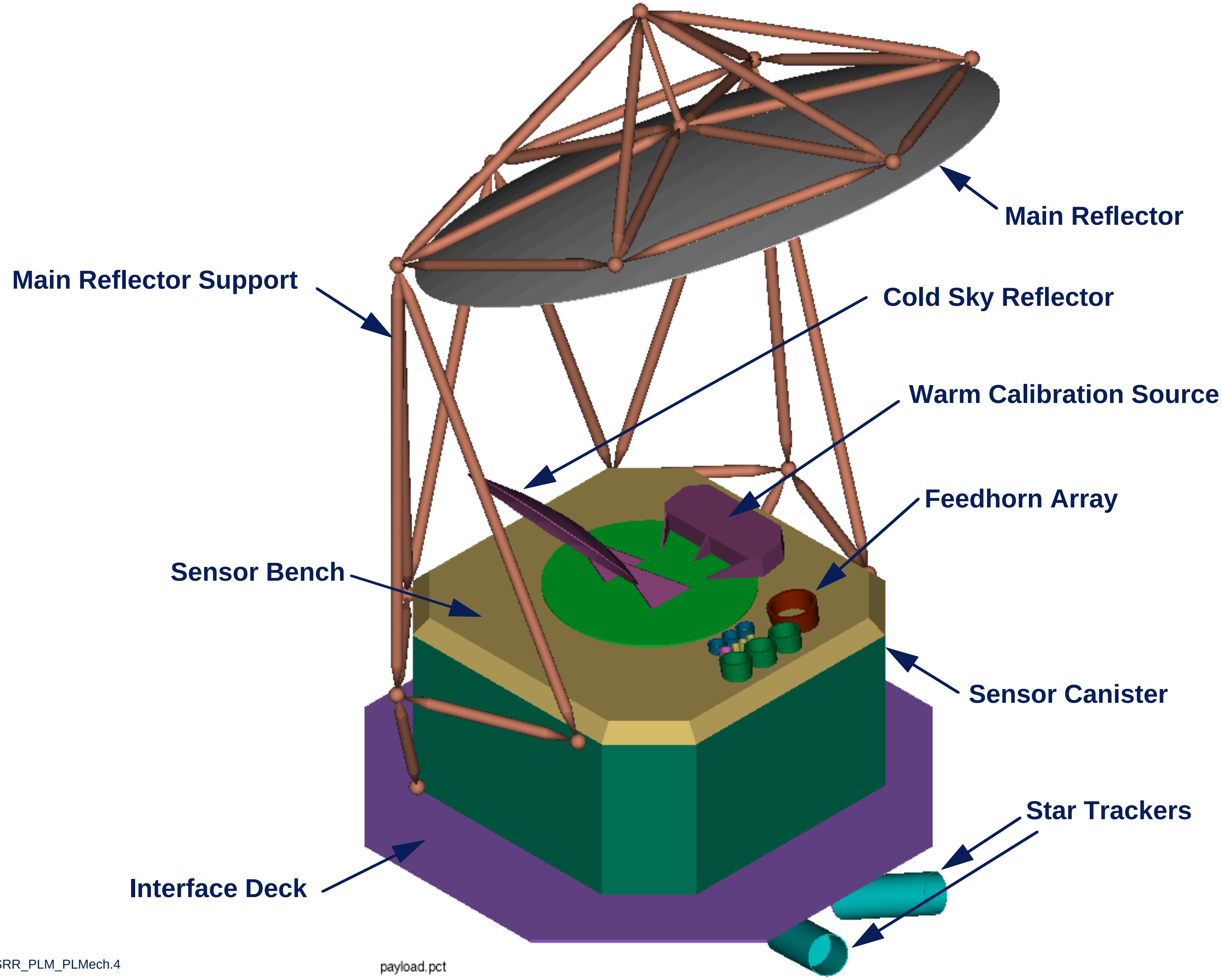
Mechanical Systems Agenda

• Payload Mechanical	B. Purdy
• Attitude Control	M. Mook
• Structures	S. Cottle
• Mechanisms	S. Koss
• Slip Ring	
• Thermal Control System	J. Kim

WindSat Concept Structure Definitions (1 of 2)



WindSat Concept Structure Definitions (2 of 2)



Payload Mechanical Error Budget

- **Allocation to Mechanical Subsystems in Pointing Knowledge Section**
- **Also Impacts Bus Interface**

Payload Weight Budget

- **30% Margin at Conceptual Design Per AIAA/ANSI Spec G-020-1992**

- **Requirement: Leave Sufficient Weight for Bus As Limited by Taurus Launch**

WINDSAT DRY WEIGHT SUMMARY		
Subsystem	Weight (lb)	Spun/Despun
Receiver	61 lb	Spun
Digital	60 lb	Spun
ACS/IMU	41 lb	Despun
Calibration	22 lb	Despun
Structures (incl. Spin Driver)	250 lb	Spun
Thermal Control	17 lb	Spun
Payload Total	451 lb	Spun & Despun
Bus Availability/Tauras Launch	849 lb	Despun
Spacecraft Total	1300 lb	

Note: Weights Include 30% Growth Margin

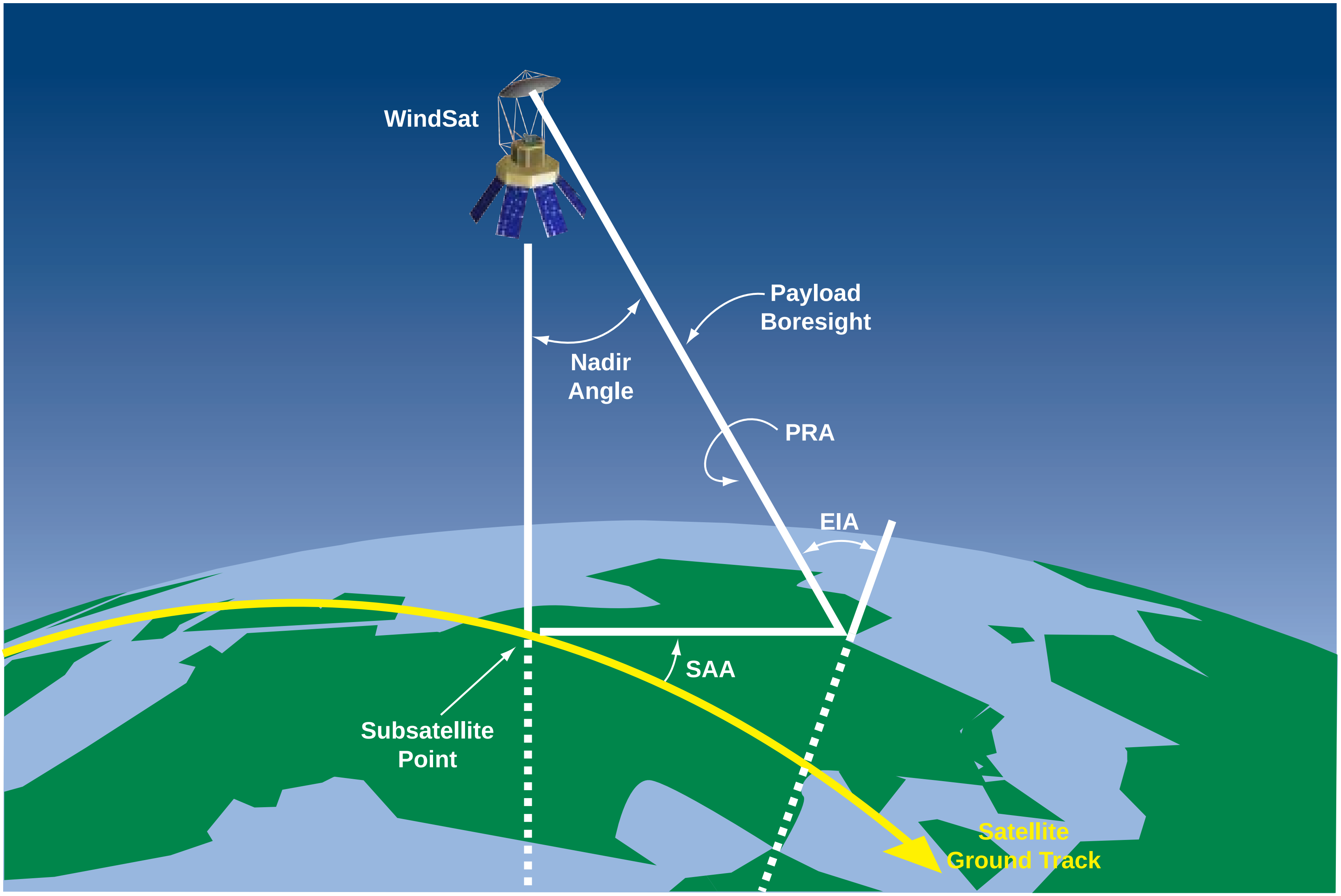
Payload Mechanical Trades

- Antenna on Top Selected Over Antenna on Bottom
  - Ease of Calibration
  - Feed and Receiver Mounting in Canister
  - Antenna on Top Wins by Wide Margin
- Non Deployed Antenna vs Deployed (Open Until 2/1/98)
  - Three Options
    - Fixed Reflector
    - Hinged Reflector Mount
    - Squatting Reflector Stowage
  - Very High Precision Required in Deployed Position
  - Deployed Beam Position Knowledge Difficulty Increases Rapidly With Mechanism Complexity
  - Packaged Volume (Bus Dependent)
    - One to Two Feet Shorter With Hinged Mount
    - Three to Six Feet Shorter With Squatting Stowage
  - Cost Increases With Mechanism Complexity
- Passive vs Active Thermal Control
  - Decide by PDR

Attitude Control Subsystem

M. Mook

Pointing Requirements



WINDSAT_pointing.eps

Pointing Requirements

- Provide Accurate Knowledge and Control of:
  - Earth Incidence Angle (EIA)
    - Nominally Constant at 53.25°
    - Nadir Angle Constant at 45°
  - Polarization Rotation Angle (PRA)
    - Nominally Constant at 0°
  - Scan Azimuth Angle (SAA)
    - Dependent on Scan Rate
  - Scan Rate
    - Constant at 29.6 RPM
- Provide Precise Geolocation of Antenna Footprint
- Limit “Jitter” of Boresight
- Minimize Impact on Other Subsystems

Pointing Requirements

BORESIGHT POINTING REQUIREMENTS Error Limits In Degrees (1 Sigma)				
	Knowledge		Control	
	Bias	Random	Bias	Random
EIA	0.05	0.05	0.80	0.25
PRA	0.05	0.05	1.00	1.00
SAA	Derived		0.15 Total	
Geolocation	1/5 Of 37 GHz Pixel		NA	
Rate Contr /Jitter	NA		1/5 Of 37 GHz Pixel Over 1 msec	

- **Notes:**
  - **Rate / Jitter Requirement Is Not a Primary Requirement But Is Desired For Imaging**
  - **Rate / Jitter Requirement Refers to Boresight Motion Relative to the Nominal Scan Trajectory**
  - **NR = No Requirement Identified**

Pointing Error Allocations
Key Definitions

- “RF Boresight to Ant Ref Bench” Refers to a Calibration Error in the Alignment of the RF Boresight (For Each Feed) to a Mechanical Reference on the Spinning Side of the Payload
- “Antenna / Sensor Bench Error” Refers to a Calibration Error in the Alignment of the Antenna Mechanical Reference to a Mechanical Reference on the Attitude Sensor Bench (on the Despun Side of the Spacecraft) and Can Include SDA Encoder Errors
- “Attitude Determination Error” Refers to the Error in Determining the Inertial Orientation of the Attitude Sensor Bench
- “Ephemeris Error” Refers to the Error in Determining the Position and Velocity Unit Vectors in the Earth Centered Inertial Frame
- “Incidence Angle Equiv of NAE” Is the Incidence Angle Produced at the Earth’S Surface Given the Nominal Orbit Altitude (850 Km) and Nadir Angle Plus the Nadir Angle Error (NAE)

Pointing Error Allocations
Key Definitions

- "Altitude Error" Is the Error in Determining the Spacecraft Altitude
- "Geoid Knowledge Error" Is the Error in Determining the Local Vertical at the Point Where the Boresight Intersects the Earth's Surface
- Nadir Angle Is the Angle Between Nadir and the Boresight (Nominally Equal to 45°)
- a Multiple of Approx. 1.3 Is Used to Calculate the Incidence Angle Equivalent of Nadir Angle Error (Based on Orbit Geometry)
- Altitude Error Contribution Is Based on 200m Ephemeris Knowledge Error

EIA and PRA Knowledge Error Allocations

EIA KNOWLEDGE		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.018	0.010
Antenna/Sensor Bench Errors	0.007	0.002
Attitude Determination Error	0.021	0.011
Ephemeris Error	0.002	0.002
Nadir Angle Error (RSS)	0.029	0.015
Incidence Equiv of NAE	0.039	0.020
Altitude Error	0.002	0.002
Geoid Knowledge Error	0.001	0.001
Incidence Angle Error (RSS)	0.039	0.020

PRA KNOWLEDGE		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.022	0.015
Antenna/Sensor Bench Errors	0.007	0.002
Attitude Determination Error	0.021	0.011
Ephemeris Error	0.002	0.002
PRA Error (RSS)	0.032	0.019

EIA Knowledge Error Allocations

SOURCE (DEG, 1 SIGMA)	BIAS	BIAS VARIATION	NOISE
RF Boresight to Ant Ref Bench	0.015		0.01
Boresight Perturbation Due To:			
Reflector Mounting	0.006		0.002
Launch Shift of Reflector	0.006		
Grav Offloading (Reflector)	0.002		
Centrifugal Gradient (Reflector)	0.000		
Strut Long Def (Water Loss + Therm)	0.001	0.004	
Feed Mounting Alignment Error	0.003	0.002	
Antenna Boresight Errors (RSS)	0.018	0.004	0.010
SDA Bearing Tilt	0.004		0.002
Sensor Bench Mounting	0.006		
Antenna/Sensor Bench Error (RSS)	0.007		0.002
Startracker Mounting	0.006		
Startracker Accuracy	0.017		0.010
IRU Mounting	0.006		
IRU Propagation Error	0.010		0.004
Attitude Determination Error (RSS)	0.021		0.011

- **RSS Values Map Directly to Higher Level Allocations on Previous Slide**
- **Bias and Bias Variation (Periodic) Terms Are RSSd at Higher Level**

PRA Knowledge Error Allocations

SOURCE (DEG, 1 SIGMA)	BIAS	BIAS VARIATION	NOISE
RF Boresight to Ant Ref Bench	0.020		0.015
Boresight Perturbation Due To:			
Reflector Mounting	0.006		0.002
Launch Shift of Reflector	0.006		
Grav Offloading (Reflector)	0.002		
Centrifugal Gradient (Reflector)	0.000		
Strut Long Def (Water Loss + Therm)	0.001	0.004	
Feed Mounting Alignment Error	0.003	0.002	
Antenna Boresight Errors (RSS)	0.022	0.004	0.015
SDA Bearing Tilt	0.004		0.002
Sensor Bench Mounting	0.006		
Antenna/Sensor Bench Error (RSS)	0.007		0.002
Startracker Mounting	0.006		
Startracker Accuracy	0.017		0.010
IRU Mounting	0.006		
IRU Propagation Error	0.010		0.004
Attitude Determination Error (RSS)	0.021		0.011

Geolocation Error Allocations

- **37 GHz "FOV" Subtends Approx. ± 0.165° in Each Direction**
- **Requirement Is 1/5 of 37 GHz Pixel (0.07°) in Each Direction (Along Scan and Normal to Scan)**
  - **1/2 Pixel Per IORD**
  - **1/5 Pixel Necessary for Post Processing**

GEOLOCATION ERRORS 1 SIGMA, DEGREES		
SOURCE	BIAS	NOISE
Nadir Angle Error (RSS)	0.029	0.015
Altitude Error	0.005	0.002
Position Error	0.005	0.002
Normal To Scan (RSS)	0.030	0.015
Normal Bias + Noise	0.045	
SAA Error (RSS)	0.031	0.018
Position Error	0.005	0.002
Along Scan (RSS)	0.031	0.018
Along Scan Bias + Noise	0.049	

- **Altitude and Position Derived Angle Errors Are Based on 200m Ephemeris Knowledge Errors**

SAA Knowledge Error Allocations

SAA KNOWLEDGE		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.018	0.010
Antenna/Sensor Bench Errors	0.012	0.010
Attitude Determination Error	0.021	0.011
Ephemeris Error	0.002	0.002
SAA Error (RSS)	0.031	0.018

SAA Knowledge Error Allocations

SOURCE (DEG, 1 SIGMA)	BIAS	BIAS VARIATION	NOISE
RF Boresight to Ant Ref Bench	0.015		0.01
Boresight Perturbation Due To:			
Reflector Mounting	0.006		0.002
Launch Shift of Reflector	0.006		
Grav Offloading (Reflector)	0.002		
Centrifugal Gradient (Reflector)	0.000		
Strut Long Def (Water Loss + Therm)	0.001	0.004	
Feed Mounting Alignment Error	0.003	0.002	
Antenna Boresight Errors (RSS)	0.018	0.004	0.010
Encoder Error	0.010		0.010
Sensor Bench Mounting	0.006		
Antenna/Sensor Bench Error (RSS)	0.012		0.010
Startracker Mounting	0.006		
Startracker Accuracy	0.017		0.010
IRU Mounting	0.006		
IRU Propagation Error	0.010		0.004
Attitude Determination Error (RSS)	0.021		0.011

EIA and PRA Control Allocations

EIA CONTROL		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.018	0.010
Antenna/Sensor Bench Errors	0.007	0.002
Att Control Error	0.141	0.030
Nadir Angle Total (RSS)	0.143	0.032
Incidence Equiv of NAE	0.190	0.041
Altitude Error	0.400	0.000
Incidence Angle Error (RSS)	0.443	0.041

PRA CONTROL		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.022	0.015
Antenna/Sensor Bench Errors	0.007	0.002
Att Control Error	0.141	0.030
PRA Error (RSS)	0.143	0.034

- **Altitude Error Allocation Corresponds to Approx. A 40 Km Error**
- **the Bias Attitude Control Error Includes the Bias and Slowly Varying Motion Due to Payload Mass Imbalance**

SAA Control Allocations
and Derived SAA Knowledge

SAA CONTROL		
1 SIGMA, DEGREES		
SOURCE	**BIAS**	**NOISE**
Antenna Boresight Errors	0.018	0.010
Antenna/Sensor Bench Errors	0.012	0.010
SDA Spin Control (Equiv. Angle Error)	0.019	0.005
Att Control Error	0.071	0.030
SAA Total (RSS)	0.076	0.034
SAA Bias + Noise	0.110	

- **SDA Spin Control Is Based on 0.006 Deg Encoder Accuracy**
- **Attitude Control Reflects Fact That Mass Imbalance Has Less Impact on SAA Control**
- **Required SAA Knowledge Remains Same As Derived From Geolocation Requirement**

Rate Control and Jitter Allocations

- There Is No Primary Requirement for Rate or Jitter Control of the Boresight Pointing
- However It Is Good Engineering Practice and Desirable for Potential Imaging That a Requirement Be Derived
- Specifically It Is Desirable That the Pixel Motion Be Less Than 1/5 Pixel From the Nominal Trajectory
- The Motion Is Separated Into a Rate Bias, Periodic Variations, and Noise
- A Rate Bias Yields a Constant Relative Motion of the Pixel
- Periodic Variations of the Pixel Trajectory Can Be Limited at Low Frequencies by Limiting the Maximum Rate of the Variations
  - This Is Far Less Limiting Than Limiting the Max Amplitude of the Variations and Is Still Sufficiently Conservative
- Periodic Variations at High Frequencies Must Be Limited by the Amplitude of These Variations
- Noise Limits Are Specified by the Variance
- The Total Range of Motion Is Given by the RSS of the Periodic and Noise Terms Added to the RSS of the Bias Terms

Rate Control and Jitter Allocations

- **Error Sources Include**
  - **SDA Controller Errors (Along Scan Error Only)**
  - **Bus ACS Controller Errors**
  - **Payload and Bus Structural Bending**
  - **Wheel Imbalance**
  - **Payload Imbalance**
- **Along Scan Rate Bias Allocation/Expected Capability**
  - **SDA Controller: <0.1% of Spin Rate or <0.18 Deg/Sec**
  - **Bus Controller: <0.01 Deg/Sec**
  - **RSS = < 0.4 Deg/Sec or Equivalently 0.0004 Deg Over 1 msec**
- **Perpendicular to Scan Rate Bias Allocation / Expected Capability**
  - **No Bias Terms Identified**

Rate Control and Jitter Allocations

- Low Frequency Periodic Allocation / Expected Capability
  - Along Scan:
    - All Frequencies Are Below 0.5 Hz and Have Amplitude Less Than 0.1 Deg
    - Result: Pixel Will Traverse 0.0003° In 1 msec
  - Perp to Scan:
    - All Frequencies Are Below 0.5 Hz and Have Amplitude Less Than 0.1 Deg
    - Result: Pixel Will Traverse 0.0003° In 1 msec
- High Frequency and Noise Allocation / Expected Capability
  - Along Scan Contributions Are Shown in Noise Column of SAA Control Error Budget and Are Less Than 0.034 Deg
  - Contributions Perpendicular to the Scan Are Shown in Noise Column of Nadir Angle Control Error Budget and Are Less Than 0.032 Deg

Rate Control and Jitter Allocations

- The 37 Ghz Pixel Motion Error Over a 1 msec Integration Period Is Primarily Due to High Frequency Motion (and Noise)

- The Resulting Motion Is Less Than 0.035 Deg Along the Scan and Normal to the Scan

Requirements Vs. Allocations

- **Allocations Are Based on Expected Capabilities**

- **Margin Is Shown at Requirements Level (and Not at Derived Requirements Level) Using Results From Allocations**

Pointing Requirements vs. Allocations (1 Sigma, Degrees)

1 Pointing Knowledge	Reqmnt	Allocation	Margin	3 Geolocation	Reqmnt	Allocation	Margin
1.1 EIA				3.1 Normal to Scan	0.07	0.045	46%
1.1.1 Bias	0.05	0.039	29%	3.2 Along Scan	0.07	0.049	35%
1.1.2 Random	0.05	0.020	155%				
1.2 PRA				4 Rate Control/Jitter			
1.2.1 Bias	0.05	0.032	56%	4.1 Normal to Scan	0.07	0.035	89%
1.2.2 Random	0.05	0.019	167%	4.2 Along Scan	0.07	0.042	57%
1.3 SAA							
1.3.1 Total	na	0.031	na				
2 Pointing Control							
2.1 EIA							
2.1.1 Bias	0.8	0.443	81%				
2.1.2 Random	0.25	0.041	506%				
2.2 PRA							
2.2.1 Bias	1	0.143	597%				
2.2.2 Random	1	0.034	2871%				
2.3 SAA							
2.3.1 Total	0.15	0.110	37%				

BUS ACS Interface Considerations

- Large Angular Momentum
  - Spinning at 30 RPM the Payload Has a Angular Momentum of 85 N-M-S Nominally Along Nadir
  - Either the Bus or the Payload Must Cancel This Momentum
  - It May Be More Efficient and Reliable for the Bus to Accomodate This, However, It Will Limit the Use of Existing Bus Designs
- Static and Dynamic Mass Imbalance
  - Payload Can Not Be Perfectly Statically and Dynamically Balanced
  - The Bus Must Still Meet the Attitude Control Requirements When Perturbed by This Imbalance
  - It Is Likely That the Bus Will Require the Payload to Trim the Mass Properties on Orbit
- SDA to Bus Alignments
  - Alignment Angles Between the Scan Encoder and the Bus Attitude Sensor Bench Must Be Very Precisely Known
  - All Angles Between the Payload and the Attitude Sensors Must Be Well Known

BUS ACS Interface Considerations

- **Attitude Determination**
  - **To Minimize the Impact of Component Alignment Errors and Thermal / Structural Distortions It Is Desired That the Attitude Sensors Be Mounted As Close to the Payload As Possible**
  - **Additionally, It Is Desired That the Attitude Sensor Data Be Time Tagged, Stored, and Transmitted Along With the Payload Data**
  - **The Bus Requires the Attitude Sensors for Attitude Control**
  - **These Considerations Indicate an Impending Trade I.E., On Which Side of the Interface Will the Attitude Sensors and Sensor Data Processing Reside**
- **Interconnected Control Systems**
  - **There Will Be a Number of Control Systems on Either Side of the Interface and They Must Work Together**
  - **Dynamics of SDA and Antenna Flexibility Must Be Considered by Each Controller Regardless of Location**
  - **Pointing Analysis <u>Must</u> Include Bus Control System Details**

Implementation/Derived Requirements

- **Attitude Determination**
  - **Sensors on Despun Payload Side of Interface**
    - **Allows for Early Assessment of Requirements**
    - **This Trade Will Be Revisited After Bus Contract Award**
  - **Sensors Will Likely Include at Least Two Star Trackers and One IRU**
  - **Requirements Are:**
    - **Sensor Bench Attitude Determination < 0.021°Per Axis and at All Times**
    - **Rate Measurement Requirement Is TBD**
  - **External Functional Requirements Are:**
    - **Power, Thermal, Structure**
    - **Data Time Tagging, Processing, Storage and Telemetry**

Implementation/Derived Requirements

- Mass Balance Mechanism
  - Include Mass Balance Mechanism on the Payload
  - Reduce Static and Dynamic Imbalance of Payload
    - Dynamic Correction From 0.2° To < 0.05° Principal Axis Misalignment
    - CG Movement of at Least TBD Inches in Each Direction Orthogonal to the Spin Axis (or Equiv Static Imbalance of TBD Oz-in)
  - Indicate Mass Positions and Accept Position Commands From the ACS
  - Low Cycle Life Required Since Positioned During Initial On-Orbit Check Out and Revised Infrequently Thereafter
- Mass Imbalance Determination (Part of ACS)
  - Determine Payload Principal Spin Axis Misalignment to < 0.025°
  - Determine the Payload Cm Offset (From Mechanical Spin Axis) or Equivalent Static Imbalance in Oz-in With an Accuracy of < TBD Oz-In
  - Calculate the Required Position Commands for the Mass Balance Mechanism
  - Ground Based Data Processing and Command Generation I.E., Mass Balance Mechanism Control Is Open Loop

Implementation/Derived Requirements

- **SDA Control**
  - **Relative Rate Control Error < .1% Of Spin Rate**
  - **Relative Angle Control Error < 0.019°**
  - **Encoder Position Error < 0.006°**
  - **SDA Motor Torque Shall Not Exceede Momentum Wheel or Reaction Wheel Motor Torque Capability**
  - **SDA Controller May Be Required to Provide Motor Torque Signal to Bus Attitude Controller**
- **Momentum Wheel and Controller**
  - **Include Momentum Wheel and Its Controller on the Payload Side**
    - **Minimizes Impact to Existing Bus Designs**
    - **This Trade Is Still Open**
  - **Requirements**
    - **Maintain Constant Angular Momentum With Variation < 0.1 N-M-S**
      - **For 85 N-M-S This Requires Speed Control With Error < 0.1%**
    - **Static and Dynamic Imbalance Requirements Are TBD but Are Derived From the Jitter Error Budget**

ACS Requirements Matrix (B/U)

Requirement Title	Bias	Random	From	To
EIA Knowledge	0.05	0.05	Top	EIA Know
PRA Knowledge	0.05	0.05	Top	PRA Know
SAA Knowledge	See Geolocation		na	SAA Know
Geolocation (knowledge)	1/5 Of 37 GHz Pixel		Top	
EIA Control	0.8	0.25		EIA Control
PRA Control	1	1		PRA Control
SAA Control	0.15 Total (Bias & Random)			SAA Control
Rate/Jitter	1/5 Of 37 GHz Pixel Over 0.8 msec			Rate/Jitter
Antenna Boresight Errors	0.018	0.010	EIA Know	RF & Mech Align
Antenna/Sensor Bench Errors	0.007	0.002	EIA Know	Struct & Mech
Attitude Determination Error	0.021	0.011	EIA Know	ACS
Ephemeris Error	0.002	0.002	EIA Know	Orb Mech
Altitude Error	0.002	0.002	EIA Know	Orb Mech
Geoid Knowledge Error	0.001	0.001	EIA Know	tbd
Antenna Boresight Errors	0.022	0.015	PRA Know	RF & Mech Align
Antenna/Sensor Bench Errors	0.007	0.002	PRA Know	Struct & Mech
Attitude Determination Error	0.021	0.011	PRA Know	ACS
Ephemeris Error	0.002	0.002	PRA Know	Orb Mech
Antenna Boresight Errors	0.018	0.010	SAA Know	RF & Mech Align
Antenna/Sensor Bench Errors	0.012	0.010	SAA Know	Struct & Mech
Attitude Determination Error	0.021	0.011	SAA Know	ACS
Ephemeris Error	0.002	0.002	SAA Know	Orb Mech
All Values In Degrees Unless Otherwise Stated				

ACS Requirements Matrix (B/U)

Requirement Title	Bias	Random	From	To
Att Contr Error	0.141	0.030	EIA Control	ACS
Altitude Error	0.400	0.000	EIA Control	Orb Mech
Att Control Error	0.141	0.030	PRA Control	ACS
Nadir Angle Error (RSS)	0.035	0.015	Geolocation	EIA Know
SAA Error (RSS)	0.037	0.018	Geolocation	SAA Know
Altitude Error	0.005	0.002	Geolocation	Orb Mech
Position Error	0.005	0.002	Geolocation	Orb Mech
Rate Bias	0.1% of 30.9 rpm		Rate/Jitter	SDA Controller/Mech
Rate Bias	0.01 °/s		Rate/Jitter	Att Controller/ACS
Low Freq Periodic	0.1° for =<0.5Hz		Rate/Jitter	SDA Controller/Mech
Low Freq Periodic	0.1° for =<0.5Hz		Rate/Jitter	Att Controller/ACS
Low Freq Periodic	0.1° for =<0.5Hz		Rate/Jitter	Structure/Mech Align
Low Freq Periodic	0.1° for =<0.5Hz		Rate/Jitter	Mass Bal./Mech/ACS
Low Freq Periodic	0.02° for 0.5<f<50Hz		Rate/Jitter	Structure/Mech Align
High Freq Periodic/Noise	0.005°		Rate/Jitter	SDA Controller/Mech
High Freq Periodic/Noise	0.03°		Rate/Jitter	Att Controller/ACS
High Freq Periodic/Noise	0.014°		Rate/Jitter	Structure/Mech Align
High Freq Periodic/Noise	incl. in Att. Contr.		Rate/Jitter	Wheel Imbalance/ACS
All Values In Degrees Unless Otherwise Stated				

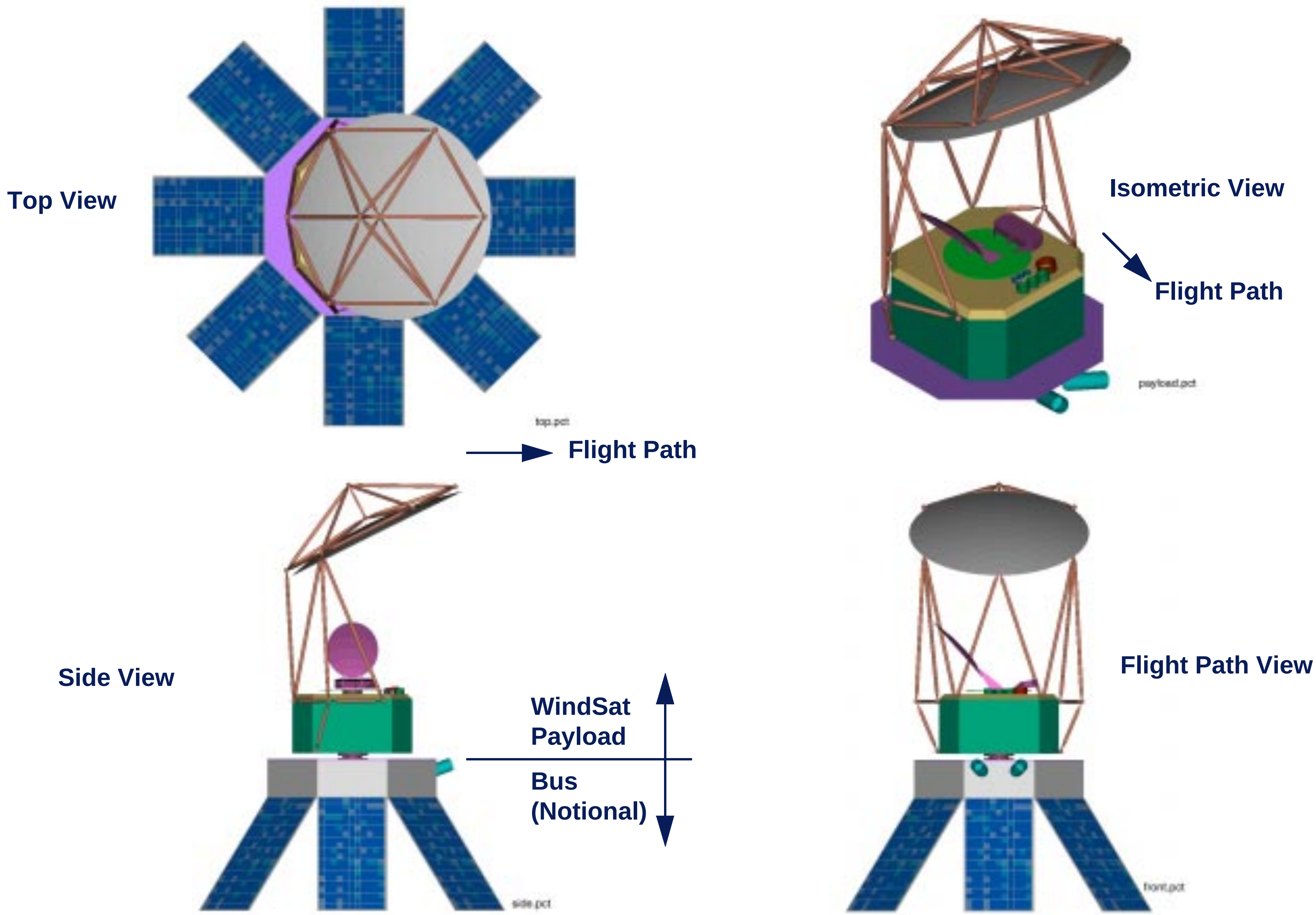
ACS Requirements Matrix (B/U)

Requirement Title	Bias	Random	From	To
SDA Rate Control	0.1% of 29.6 rpm		ACS: PL Mass Imbal.	SDA Controller/Mech
Mass Bal. Mech. Oper. Range	tbd		ACS	Mass Bal./Mech
Mass Bal. Determination	tbd		Mech	ACS
Mass Bal. Det. Processing	tbd		ACS	tbd
ACS Data Time Tagging	tbd		ACS	DH&C
ACS Data Processing	tbd		ACS	DH&C
ACS Data Time Storage	tbd		ACS	DH&C
ACS Power	tbd		ACS	EPS
ACS Command & Telemetry	tbd		ACS	Comms
All Values In Degrees Unless Otherwise Stated				

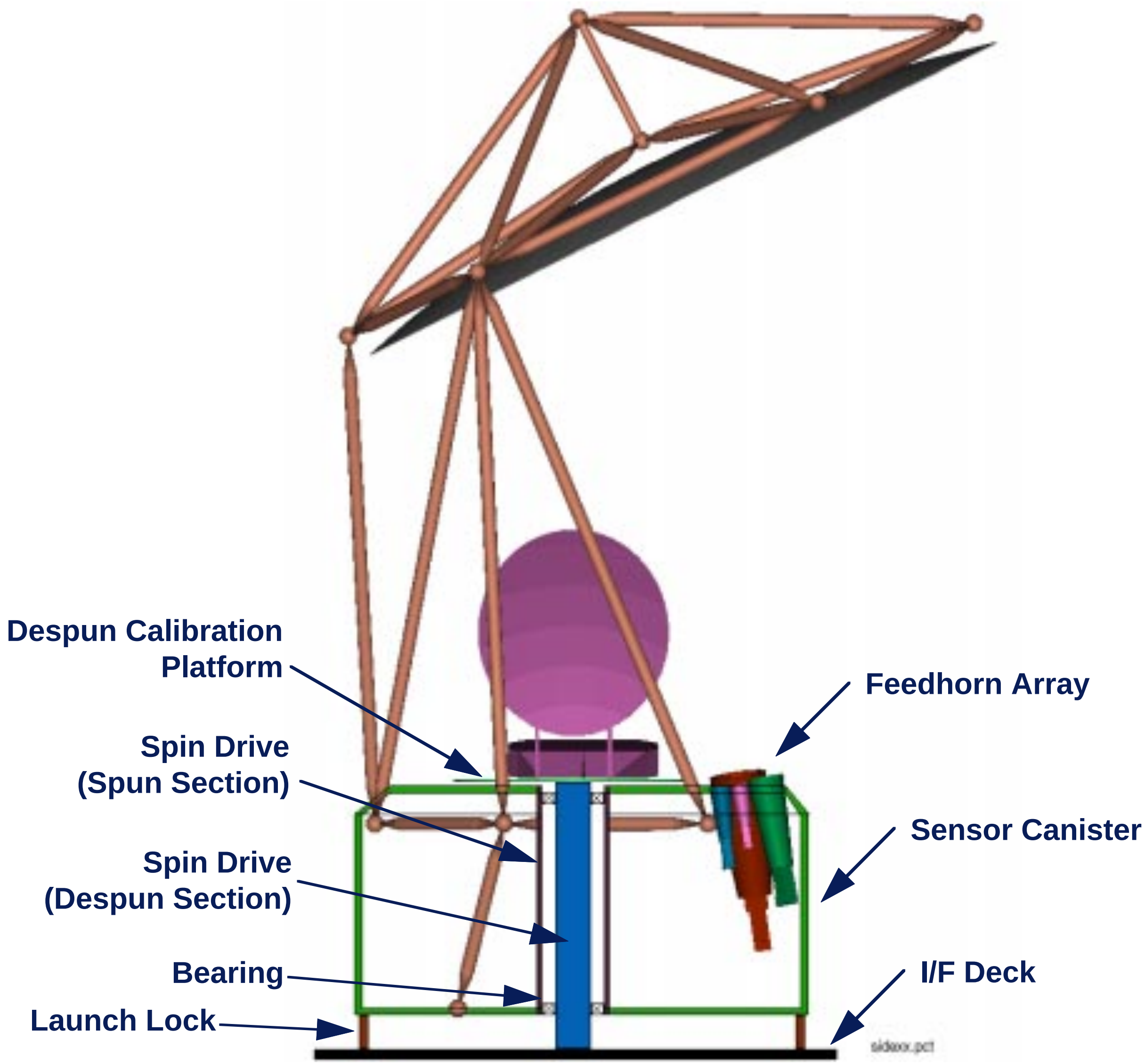
Structures

Cottle

WindSat Concept Review



WindSat Payload Cross-Section



Structure Requirements (1 of 2)

Item	Requirement	Type	Derived/Allocated
Attitude Bench	Location Under Trade Study. Location Determined by PDR	Functional	Derived
Attitude Bench	Despun	Functional	Allocated
Attitude Bench	Sufficient Area for Two Star Trackers And IRU	Functional	Allocated
Cold Sky Reflector	Exact Lateral Location And Configuration Under Study. Will Be Determined by PDR	Performance	Derived
Cold Sky Reflector	Despun	Performance	Allocated
Feedhorns	Array Centered on Main Reflector Focal Point	Functional	Allocated
Feedhorns	Post-Assembly Alignment Capability Per Alignments Chart	Functional	Derived
Feedhorns	Post-Assembly Alignment Measurement to Be Optical for Maximum Precision	Derived	Functional
Feedhorns	Keep Debris Out	Performance	Derived
General Structures	May Not Interfere With Sensor Scan of Earth	Constraint	Allocated
General Structures	Survive Launch, Static Loads, Vibration & Acoustic Environments	Performance	Allocated
General Structures	Maintain Alignments After Launch	Performance	Allocated
General Structures	Locate Within 76” Dia Envelope to Fit Within 80.9” Dia Taurus Fairing (Includes Margin)	Constraint	Allocated
General Structures	No On-Orbit Structures Shall Exhibit Significant Response to a 0.5 Hz Disturbance	Performance	Derived
Main Reflector	Center Located 68.4” Above Feedhorns	Performance	Allocated
Main Reflector	Low CTE for Minimum Thermal Distortion. Maximum Allowable Distortion to ± .004”	Performance	Derived

Structure Requirements (2 of 2)

Item	Requirement	Type	Derived/Allocated
Main Reflector	Diameter Limit of 72” For Fit in Taurus Envelope (Includes Margin)	Constraint	Allocated
Reflector Supports	Sufficiently Stiff and Strong to Support Main Reflector - Must Survive Launch Loads	Performance	Derived
Reflector Supports	Low CTE for Minimum Thermally Induced Reflector Rotation. Maximum Angular Variation +/-0.003°	Performance	Allocated
Reflector Supports	Locate Within 76” Dia Envelope About Reflector	Constraint	Allocated
Sensor Bench	Support Feedhorn Array and Provide Alignment Capability	Functional	Allocated
Sensor Canister	Support Sensor Bench and Provide Enclosure for Electronics	Functional	Allocated
Sensor Canister	Minimize Height. Lower Limit Is 17” Based on Fit of 6.8GHz Feedhorn	Constraint	Derived
Spin Balance	Payload Dynamically Balanced for Minimal on Orbit Adjustment	Performance	Derived
Warm Calibration Source	Located Above Feedhorns During Calibration Sweep	Performance	Allocated
Warm Calibration Source	Despun	Performance	Allocated

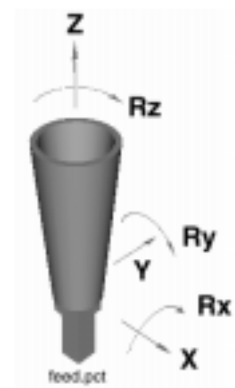
Feedhorn Adjustment Requirements (1 of 2)

37GHz / VH

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

18.7GHz / VH

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II



37GHz / 45 Degree

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

18.7GHz / 45 Degree

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

37GHz / CP

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz		(na)	

18.7GHz / CP

Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz		(na)	

<u>Legend</u>

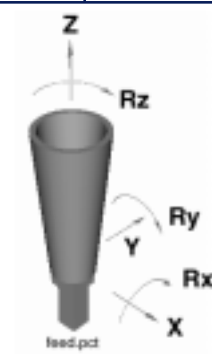
(nr) = adjustment is not required; mechanical assembly will achieve required accuracy.
(na) = adjustment is not required; circular polarization is not sensitive to rotation.
I = on bench and lock in place
II = at range and lock in place

Feedhorn Adjustment Requirements (2 of 2)

10.7GHz / VH			
Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

6.8GHz / VH			
Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

10.7GHz / 45 Degree			
Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II



10.7GHz / CP			
Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz		(na)	

23.8GHz / VH			
Motion	Range	Accuracy	When
X	(nr)	± 0.012”	I
Y	(nr)	± 0.012”	I
Z	± 0.5”	± 0.1”	II
Rx	(nr)	± 0.5°	I
Ry	(nr)	± 0.5°	I
Rz	± 1°	± 0.05°	II

Legend

(nr) = adjustment is not required; mechanical assembly will achieve required accuracy.
(na) = adjustment is not required; circular polarization is not sensitive to rotation.
I = on bench and lock in place
II = at range and lock in place

Completed Structures Trade Studies/Analyses

- Structural Analysis to Determine Maximum Reflector Diameter for Fit Within Taurus Fairing With Sway Space Margin
  - Single Amplitude Dynamic Displacement of 2” Results in Maximum Reflector Diameter of 72” for Fit in Taurus Fairing
  - Analysis to Be Refined by PDR
- Feedhorn Alignment: Mechanical Vs. Electrical
  - This Trade Covered in Antenna Section
- Feedhorn Post-Assembly Alignment Measurement: Mechanical Vs. Optical
  - High Precision of Rotation Knowledge (0.03 Degree) Exceeds Accuracy Capability of Mechanical Measurements. Optical Methods Provide Required Accuracy (+/- 0.0014 Degree)

Structures Trade Studies Completed

- Main Reflector: Metallic vs. Composite
  - Minimum Weight and Thermal Distortion Required
    - High Stiffness-to-Weight Ratio = Composite
    - Very Low CTE = Composite
  - Composite Is Preferred Material

Structures Trade Studies To Be Performed

- **Main Reflector Structure**
  - **Truss Frame, Monocoque, or Combination Designs Considered**
  - **Optimal Design for Weight, Stiffness, and Despun Structure Clearance**
  - **Study Complete by PDR**
- **Attitude Control Bench Location**
  - **Ideally Located Despun Above Sensor Bench - Gives Lowest Alignment Errors**
  - **Lack Of Real Estate Above Sensor Bench May Drive Bench to Interface Deck. Provides Acceptable Alignment Errors**
  - **Study Complete by PDR**

Interfaces To External Subsystems

- Sensor Bench-to-Canister and Spin Drive Interface
  - Drives Canister Materials Selection
  - Drives Sensor Bench Alignment Stability (Thermal)
- Sensor Bench / Canister Assembly
  - Interfaces With All Major Structure Subsystems
  - Main Reflector Interface is Critical
  - Thermal Stability of Structures is Critical to Maintain Alignment Tolerances

Implementation Plan

- **Make vs. Buy Main Reflector Support:**
  - **Decide by PDR**
- **Long Lead Composite Structures:**
  - **Identify by PDR**
- **Other Long Lead Structures TBD (by PDR)**

Unique Test Equipment

- Spin Balance Machine Available at NRL
- Theodolite Available at NRL
- Rotary Table Available at NRL
- 3-Axis Boresight Calibration Gimbal Availability TBD

Payload Mechanisms

Koss

Mechanisms

- **Payload Mechanisms Required**
  - **SDA (Scan Drive Assembly)**
  - **Canister Launch Lock Mechanism**
  - **On Orbit Balance Mechanism**

Mechanisms Requirements (1 of 2)

BALANCE MECHANISM			
PARAMETER	VALUE	SOURCE	DESIGN
Provide Capability For On Orbit Static Balance	TBD	Attitude Control Systems	TBD
Provide Capability For On Orbit Dynamic Balance	< 0.1° Principle Axes Misalignment	Attitude Control Systems	<0.01° Principle Axes Misalignment
Life (Ground Test + Every 6 Months on Orbit)	25 Cycles Each	Payload Mechanisms	50 Cycles Each

Mechanisms Requirements (2 of 2)

SDA/SCAN DRIVE ASSEMBLY			
PARAMETER	VALUE	SOURCE	DESIGN
Accommodate Static Pass Thru Pedestal	-	Structures & Mechanisms	Comply
Off Load SDA During Launch	-	Payload Mechanisms	Launch Lock To Offload
Length Of SDA	= Length of Canister	Structures & Mechanisms	Comply ≈ 24 inches TBR
Rotational Speed	29.6 RPM (Outer Race Rotation)	Mission Science	Capable of Speeds 10-40 RPM
Speed Accuracy	± 0.1%	Attitude Control Systems	± 0.01%
Encoder Position Accuracy	< 0.0055°	Attitude Control Systems	<0.0014°
1X/Rev Reference Mark Accuracy	< 0.0055°	Attitude Control Systems	<0.0014°
Scan Drive Mechanical Wobble/Runout	<0.008°	Attitude Control Systems	0.004°
Payload 1st Structural Mode / Deployed	Avoid Interaction w/Other Control & Structural Modes	Structures & Attitude Control Systems	Will Comply
Life	3 Years / 49 Million Revs	Program Management	Test 98 Million Revs

Payload Mechanisms
Trade Studies

- Trade Studies to Arrive at Preliminary Design
  - Make or Buy SDA
    - Type of Feedback Device (Encoder/Resolver/Inductosyn)
  - Make or Buy Canister Launch Lock Mechanism
    - Type of Mechanism
      - Diaphragm/Marmon Clamp or Restraining Arms
  - Make or Buy Balance Mass Mechanism
    - Type of Mechanism
      - Leadscrew or Cable/Pulley Drive
  - Deployed or Fixed Reflector Structure
    - Fixed
      - Pros: Simple/Reliable/Repeatable
      - Cons: Tall Payload (> 9 ft), Low (Relative) Stiffness
    - Deployable
      - Pros: Shorter Payload, Higher Stiffness (Likely)
      - Cons: Higher Cost, More Complex/Less Reliable/Less Repeatable

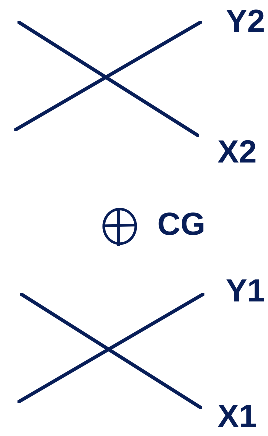
Payload Mechanisms
Interfaces to External Subsystems

- Interfaces to External Subsystems
  - Launch Lock Mechanism
    - Release Device Initiate Electronics / Software / EPS Power
  - Scan Drive Motor
    - Software / EPS Power / ACS
  - Scan Drive Encoder
    - Data Handling
  - Balance Mechanism
    - Balance Motor Drive Software / EPS Power / ACS
  - All Mechanisms
    - TBD Telemetry

Payload Mechanisms
SDA/Scan Drive

- **Design Concept**
  - **SDA/Scan Drive ≈ 30 lb, 1” ID X 6” OD X 16” Long**
  - **Includes Motor, Encoder, Main Bearings/Support Structure, and Slip Ring Assembly**
- **Implementation Plan**
  - **SDA Will Be Long Lead**
    - ***Make/Buy Trade Study***
  - **Vendor Availability**
    - **Several Qualified Vendors for Whole Subsystem or Individual Components**
- **Unique Test Equipment**
  - **Life Test Set**

Mechanisms
Balance Mass Mechanism



- **4 Trim Balance Mass Leadscrews (X and Y Axes in 2 Planes)**
  - **Command From Ground Based Determination of on Orbit Wobble**
  - **Operate Roughly Once Every Six Months**
  - **Most Likely Motor/Screw Is Scaled Version of Astro Instrument CT1-A Which Has Flight Heritage (Qualification Testing Will Be Performed)**

Mechanisms
Balance Mass Mechanism

- **Implementation Plan**
  - **6 Month Delivery for Balance Mass Mechanisms and Drive Elex**
    - **Motor/Leadscrew and Drive Electronics Will Be Purchased**
  - **Vendor Availability**
    - **Several Qualified Vendors for Whole Subsystem or Individual Components**
- **Unique Test Equipment**
  - **None**

Payload Slip Ring Subsystem

- Slip Rings Provide
  - Power to Rotating Canister Components
  - Serial Telemetry Data From Radiometer Payload
  - Serial Command Data to Radiometer Payload
  - Timing Reference From Radiometer Payload (GPS)
  - Basic Command and Control Interfaces With T and C

Payload Slip Ring Subsystem Derived Requirements

SLIP RINGS			
PARAMETER	VALUE	SOURCE	DESIGN
Slip Ring Power & Signal Channels	12 Power,18 Signal Rings (See Table)	Payload Electronics	12 Spare Pwr 10 Spare Signal Rings
Slip Ring Channel Redundancy	100% Redundant Rings	Payload Electronics	100% Redundant Rings
Data Channel Noise	(See Table)	Payload Electronics	? Predicted, Life Test to Verify Compliance
Data Channel Crosstalk	-40 dB	Payload Electronics	Dedicated Shield Rings, ? Predicted, Life Test to Verify Compliance
Isolation Resistance	100 MOhm @ 500V DC	Payload Electronics	? Predicted, Life Test to Verify Compliance
Rotational Speed	29.6 rpm (Outer Race Rotation)	Mission Science	Capable of Speeds 10-40 rpm
Stationary Center Torque Tube	TBD Inches	Payload Elex & ACS	1 Inch Through Bore
Test Connectors	Accessible Test Port Connectors	Payload Electronics	Test Port Connectors Accessible At System Level Integration
Life	3 Years / 49 Million Revs	Program Management	98 Million Revs

Slip Ring Trade Studies

- Major Trades
  - Contacting Slip Ring Design?
    - Gold Filament on Gold Rings W/Oil
    - Composite Brush / Silver Rings
    - Oil Impregnated Composite Brush / Gold or Silver Rings
    - Gold Alloy Fiber Brush / Gold Rings
    - Gold Plated Roll Rings
  - Noncontacting Slip Ring Design?
    - RF Coupled Signal Transfer
    - Inductive Power and or Signal Transfer
    - Resonating Capacitive Power and or Signal Transfer
    - Off Axis Fiber Optic Rotary Joint Signal Transfer
  - Contacting Power Rings With Noncontacting Signal/Data Rings?
  - *Trade Study Closure Deadline - Payload PDR 4/1/98*

Slip Rings
Design Concept

Function	# of Rings	Max. Voltage	Max. Current	Max Resist.	Frequency
24-36V Bus Voltage	6	36 V	6A	0.1 ohm	
24-36V Bus Return	6	36V	6A	0.1 ohm	
Spare Power Rings	12	36V	6A	0.1 ohm	
Ground Ref.	2	5V	100 mA	10 ohm	1 MHz
Differential Serial Cmd In	4	5V	100 mA	100 ohm	100 kHz
Differential Serial Data Out	4	5V	100 mA	100 ohm	1 MHz
Differential Data Dedicated Shield	4	5V	100 mA	10 ohm	1 MHz
Payload On/Off Indicator	2	5V	100 mA	10 ohm	100 Hz
Analog Temp TLM	2	10V	100 mA	100 ohm	1 Hz
Spare Signal Rings	10	5V	100mA	10 ohm	1 MHz

100% Redundant Rings Shown

On Hand Representative Slip Ring Capsule
1” ID X 5” OD X 5” Long, Mass ≈ 5 lb

Payload Slip Ring Subsystem

- Interfaces to External Subsystems: EPS and Data Handling, S/C Structure
- Implementation Plan
  - Slip Ring Lead Time: ≈ 6 Months ARO (Purchased Item)
  - Many Vendors of Contacting Slip Rings
    - Exc. Roll Rings (Honeywell Only) and Fiber Brushes (Litton Only)
  - Unique Vendors Noncontacting Designs
- Unique Test Equipment Required
  - Dedicated Life Test Set
    - Test Chamber, High Freq DAQ
- *Plan to Do High Speed Digital Characterization Testing on Residual Hardware Gold on Gold Slip Ring Assembly Prior to PDR to Aid in Trade Study*

Thermal Control Subsystem

Kim

TCS Derived Requirements

PAYLOAD COMPONENT	REQUIREMENTS	COMMENTS
Main Reflector **- Dish** **- Support Struts**	 TBD TBD	 TBD ΔT Requirement for Deflection TBD ΔT Requirement for Deflection
Calibration Source **- Hot Blackbody** **- Cold Reflector**	 250 to 330 K 0.05°C/20 to 30 ms <0.1°C Gradient ±0.10 Measurement Accuracy TBD	 Possible ΔT Requirement Possible ΔT
Feedhorns	None	Passive Element
Receiver Assembly **- Isolator** **- Attenuator** **- Low Noise Amplifier and Gain Amplifier** **- Filter** **- Detector** **- Detector Electronics**	 None 0 to 40°C 0 to 40°C ΔT < 0.01 °C/sec 0 to 40°C 0 to 40°C ΔT<0.01°C/sec 0 to 40°C	 Passive Element
Scan Drive Assembly	0 to 40°C	Lubricant Viscosity
PCU	0 to 40°C	Baseplate Mounting Interface Requirement
SSDR	0 to 40°C	
SCU	0 to 40°C	
Scan Drive Controller	0 to 40°C	
ISU	0 to 40°C	

TCS Allocated Requirements/ Design Parameters

- Environmental Fluxes:
  - Solar: 1280 to 1420 W/m^2
  - Albedo: 0.28 to 0.32
  - Earth: 227 to 240 W/m^2
- Multi-Layer Insulation Effective Emittance:
  - 0.01 to 0.03
- Orbital Parameters:
  - 850 km Altitude, 55 Deg Inclination
  - Beta Angle Variation: -90 to 90 Deg
- Attitude:
  - 29.6 rpm Spin
  - Spin Axis Earth Pointing

Component Power

- **Major Power Dissipaters**

Payload Components	Power Per Unit (W)	Total Power (W)
Receiver Assemblies		
• LNA	2.4 – 3.6	61.2
• Amplifier	3.6 – 4.2	84.0
• Detector Electronics	1.8	19.8
• A/D Converter	44	44
TOTAL:		209
ACS (Despun)	N/A	34
Data Handling Subsystem	156.4	156.4

- **Power Numbers Do Not Reflect 50% System Power Margin**

Other TCS Design Considerations

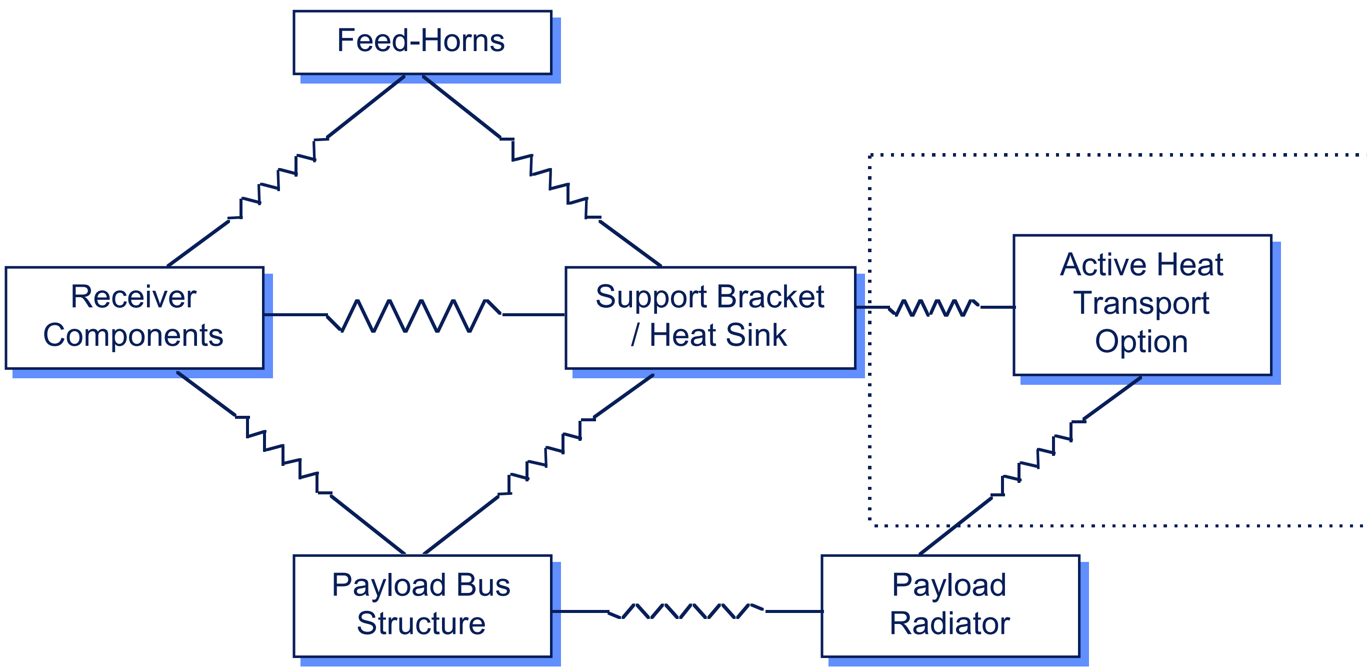
- The Receiver Assembly Electronics Components Are the Highest Heat Dissipating Payload Component
  - Components Will Be Detached From the Radiator Heat Sinks
  - Heat Transport From Receiver Assembly to a Remote Radiator Must Be Provided
- Hot Calibration Source Is Detached From the Payload Bus - Need to Provide Passive or Active Means of Independent Temperature Control (Within Requirements)
  - Passive Preferred
- Main Antenna Dish Alignment Sensitive to Support Structure Temperature Gradients
- Other Possible Design Driver:
  - Minimize Temperature Gradients Along Payload Bus Structure
- Future Consideration:
  - Specular Reflection of Sun and/or Earth Albedo From Silverized Teflon Taped Radiator Surfaces to Reflector Dish

TCS Design (1 of 3)

- **All Non-Radiator or Aperture External Surfaces Covered With Multi-Layer Insulation (MLI) - Non Specularly Reflective Outer Layer**
- **Estimated Total Weight: 10 Lbs.**
- **Radiator Surfaces Will Be Covered With Silverized Teflon Tape and/or High Emissivity White Paint (If Diffuse Solar Reflection Is Required)**
- **Polyimid Film (Kapton) Heaters and Bi-Metallic Thermostats Circuits Used to Maintain Minimum Temperature Requirements for Components Inside Payload Bus and the Hot Calibration Source (If Needed)**
- **TBD Heater Power Requirements**
- **Internal Structure Surfaces and Components Will Be Provided With Desirable Thermal Surface Optical Properties Through Use of Paints, Processes, and Tapes**
- **Back Side of the Main Reflector Dish Will Be Covered With MLI to Minimize Gradients Across Composite Facesheet**

TCS Design (2 of 3)

- **Thermal Management of Receiver Components Will Require Trade Studies and Further Design / Analysis to Develop Optimal Thermal Design**



TCS Design (3 of 3)

- **Receiver Component Support Bracket / Heat Sink Must be Sized to Moderate LNA Temperature Change Within 0.01 Deg C/sec.**
  - **$Mass X C_p X \Delta T / \Delta time = Q_{in} - Q_{out}$: Size Mass to Accommodate Difference in Dissipated Heat and Rejected Heat**
- **Direct Heat Path Between Bracket and Radiator May be Required to Meet Absolute Component Operating Temperature Requirements**

Integration and Test

Purdy

Integration and Test

- Engineering Model for Payload Prior to Flight Build
  - Separate Electrical / RF and Mechanical Engineering Models
  - Form Fit and Function
  - Compromises on Parts to Minimize Schedule and Cost
- Flight Build
  - Full Configuration Management
- Judged to Be Best Combination of Low Risk / Low Cost
  - Good History on This Approach at NRL

Test Philosophy (1 of 2)

Environmental and Performance Tests Are Required to Assure Mission Success

- **<u>Environmental Tests</u> - Verify Ability to Survive Launch and On-Orbit Environments**
- **Vibro-Acoustic: Combined Acoustic and Low Frequency Axial Random Vibration Simulates Launch and Ascent Dynamic Environments**
- **Random Vibe: Low Frequency Lateral Random Vibration Simulates Launch and Ascent Dynamic Environments**
- **Quasi-Static: Simulates Low Frequency and Steady State Loads Due to Launch, Ascent and Mission and Operations**
- **Modal Survey: Used to Determine Natural Frequencies, Damping, and Mode Shapes of the Structure**
- **Pyro-Shock: Map Shock Acceleration Response of Structure Due to Separation Device Activation**
- **TDVT: Verify Thermal Model at Steady State and Transient Conditions**

Test Philosophy (2 of 2)

- <u>Functional and Performance Tests</u> - Verify Payload Performance and Operation
- Spin Balance and Mass Properties
- Mechanism Deployment and Operation Testing
- Electronics Functional and Performance Checkouts
- Thermal Vacuum Testing Verifies Payload Performance in Expected Mission Environments
- EMI / EMC Testing Determines Self-Compatibility, Measures Radiated Emissions, and Susceptibility to RF Radiation Environments

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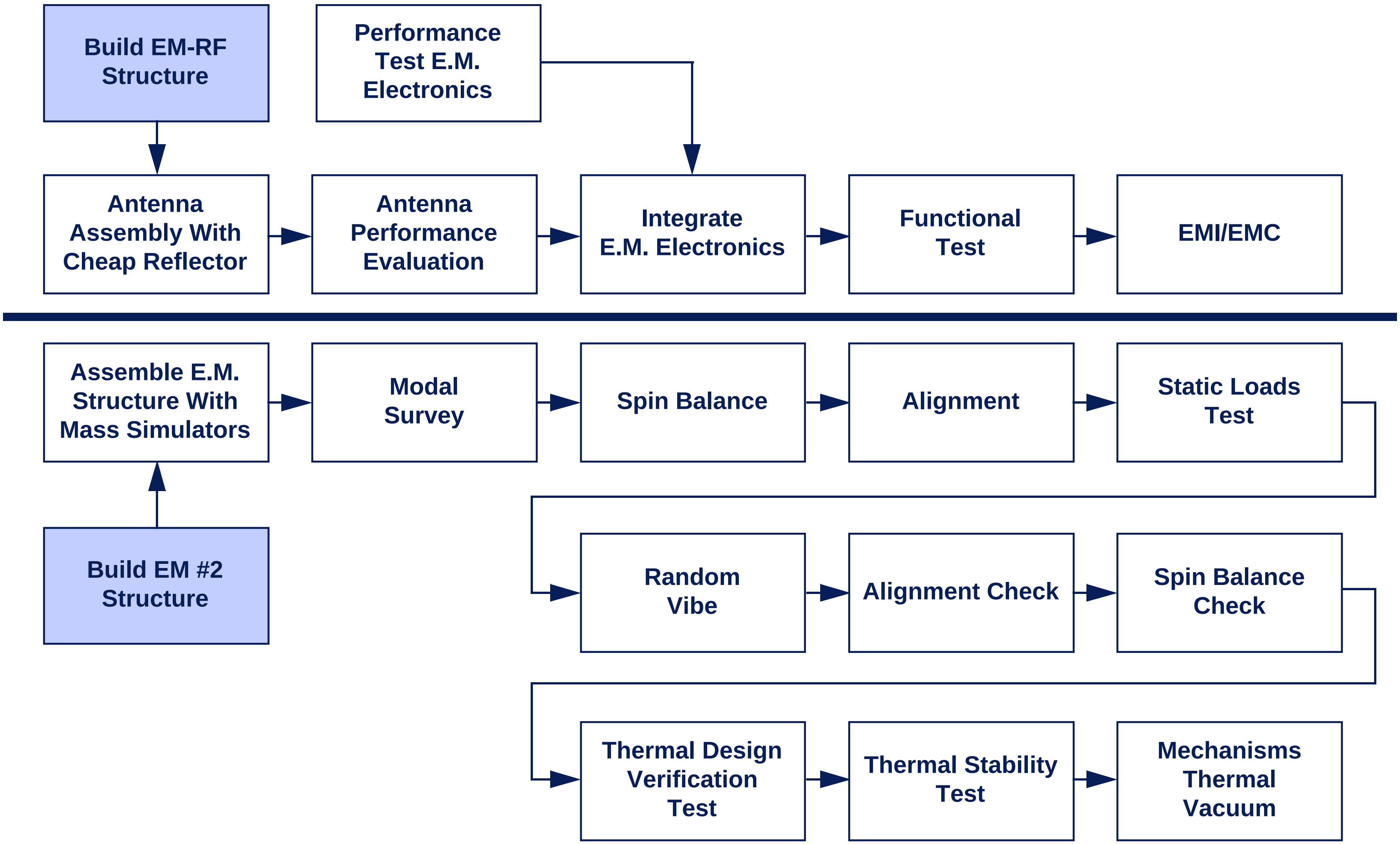
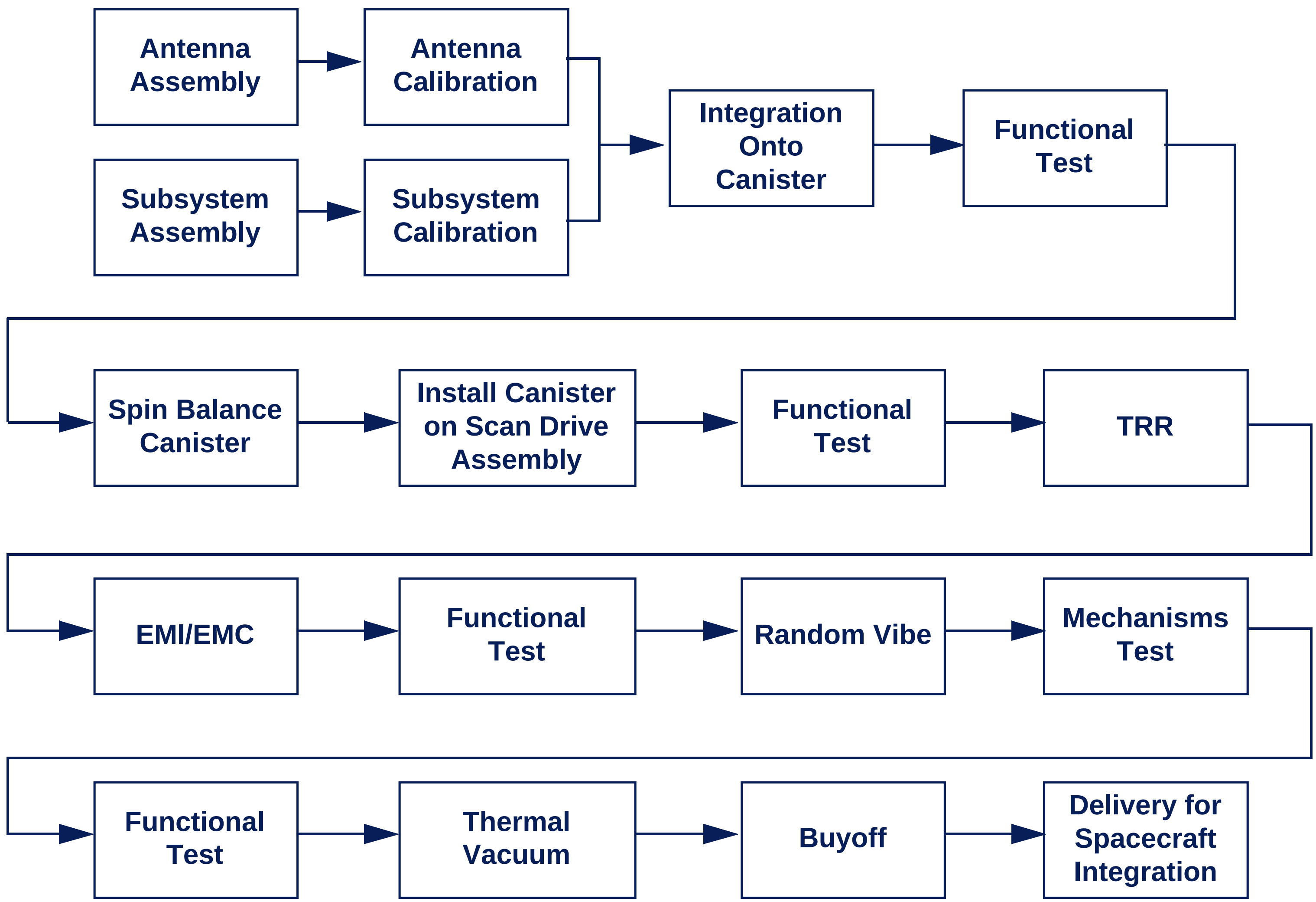
- Test Levels From Host Specifications and / or Derived From Launch Vehicle Environments
- Non-Flight Engineering Model (Mass and Stiffness Simulator) May Be Used for Early Verification Testing

I&T Mechanical Engineering Model Hardware



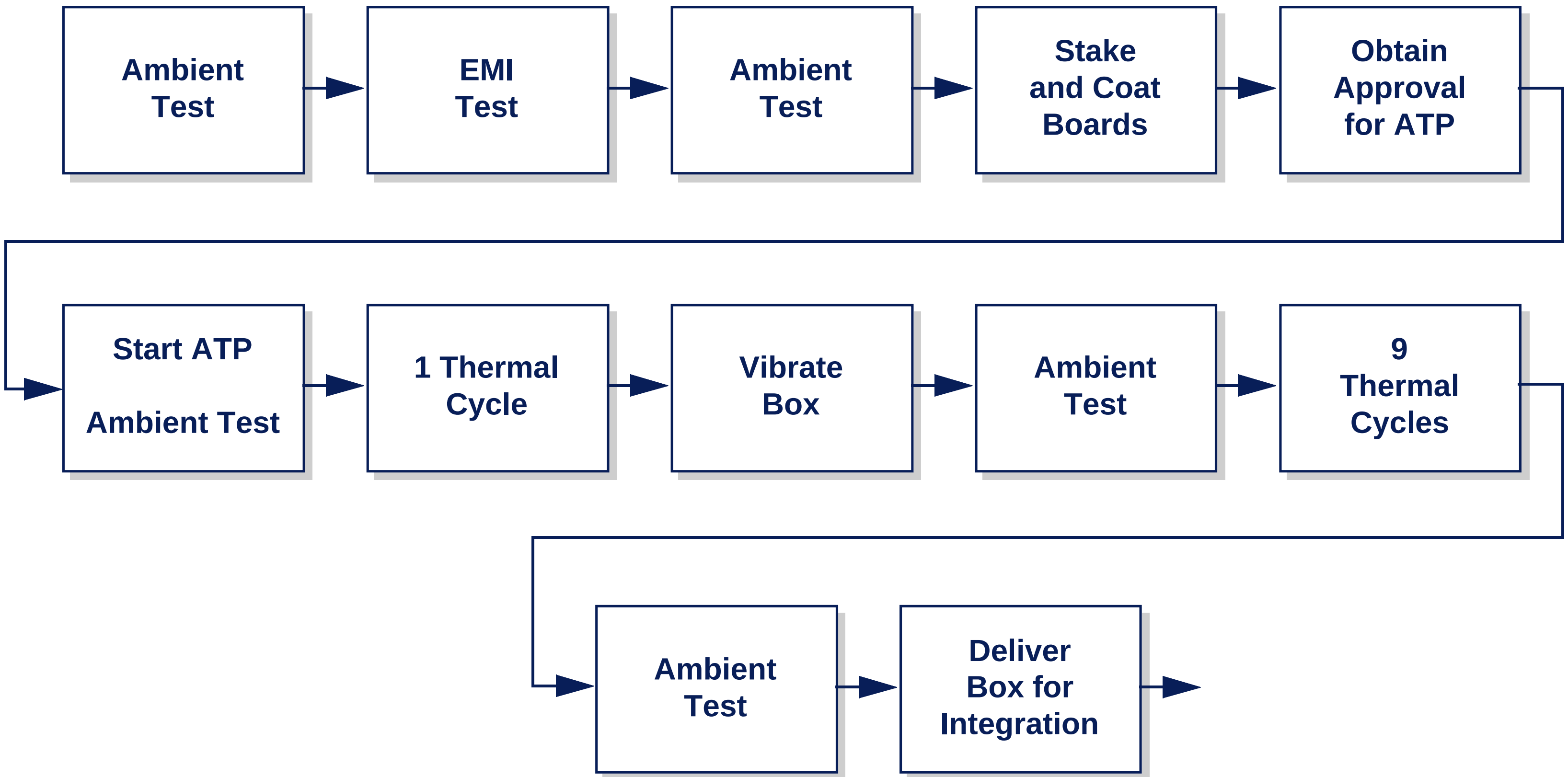
I&T Flight Hardware



Parts Program

- Selection
  - Existing NRL Flight Stock of Screened Parts
  - MIL-STD-975, Grade 2 Parts List, When Applicable
  - MIL-STD-883 Class B Microcircuits
  - JANTXV, JANTX Semiconductor Devices
  - Passive Devices Procured Under Established Reliability Level of RSS and RRS
  - Semi-Custom Parts (e.g., DC/DC Conv.) Procured at the Class B Equivalent Level
  - Parts Able to Withstand Total Dose Level of 20 krads
- Qualification
  - No Additional Screening Is Planned at the Part Level Upon Delivery of Parts
  - No DPA Is Planned on Received Parts
- Acquisition
  - Purchase From Known Vendors With Good History
  - Require Certificate of Compliance
  - Consult With Parts Engineer When Needed
- Application
  - Parts Will Be Derated According to Established NRL Guidelines Per SSD-D-210

Box Level Test Flow



- **Total of 200 Hours Burn-In**

Reliability and Safety

Spencer

Product Risk Mitigation / Reliability

- No Numerical Reliability Analysis Is Planned
- Informal System FMEA Performed Will Be Performed by CDR to Determine Acceptable Risk of Failure of Specific Components/Subsystems to Mission
  - Review of FMEA Will Be Done at Buyoff
- The WindSat Program Will Implement Redundancy in Its Design Only Where It Is Necessary and Smart to Do So
- Where Feasible, WindSat Will Have Spares at the Component Level to Provide Schedule Recoverability in the Event of an I&T Anomaly
- Use Best Available Electronic Components Per the WindSat Parts Plan
- WindSat Will Use the Established NCST Configuration Management and Product Assurance Plans
- Component / System engineering, qualification, and development models will be developed where necessary to reduce risk.
- Components and Systems Will Have Test Verification of Performance to Electrical and Environmental Extremes to Verify Performance and Reliability

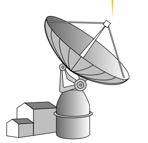
Range Safety

- The WindSat Program Is Familiar With Range Safety Concerns, Operations, and Practices
- The Program Hardware and Personnel Will Conform to EWR 127-1
- At Present the Payload Has Identified No Hazardous Materials, Pressure Vessels, Radiation Sources, or High-Voltage Sources
- At Present, the WindSat PayloadMay Use Explosive Mechanism for Marmon Clamp
- WindSat Has Not Identified Any Special Handling Requirements, but May Be Susceptible to Range Induced EMI

Calibration / Validation

G. Poe

Why WindSat Cal/Val?



grnd_station.eps

Calibration

- Absolute Accuracy
- Polarization Purity
- Geolocation Accuracy
- Essential Archival Products

Validation

- Wind Vector
- SST
- Water Vapor
- Cloud Water

Real Time

User

Archive

Satisfies

Mission Success

- Passive Microwave Polarimetric Sensing of Global Ocean Wind Vector
- Risk Reduction for NPOESS
- Quasi-Operational Products

SSM/I Cal/Val Results

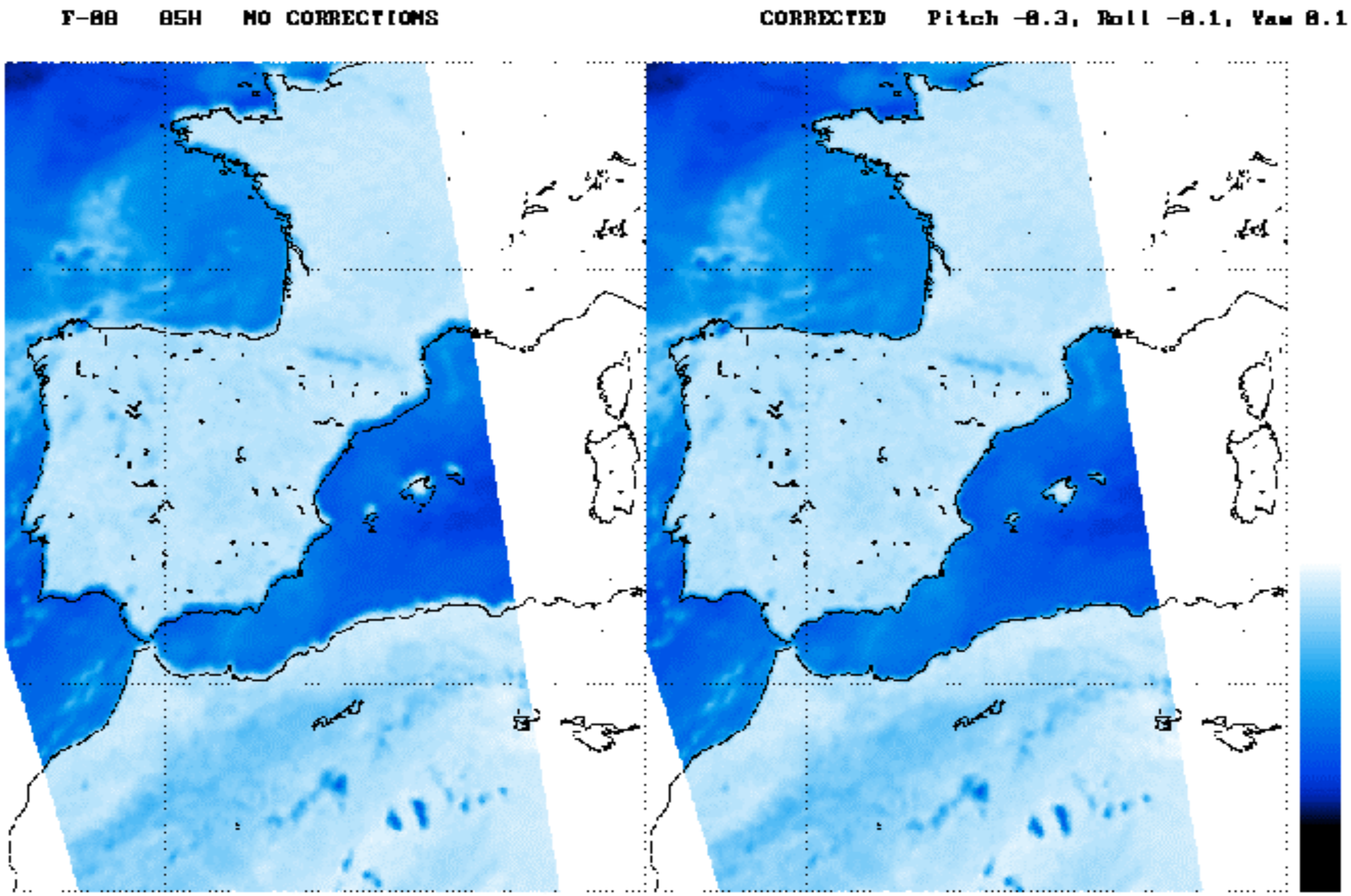
First Cal/Val: F8

Before	After	SPEC
• Geolocation Error > 50 Km	• Geolocation Error < 7 Km	7 Km
• Sea Windspeed Error > 6 m/s	• Sea Windspeed Error < 1.9 m/s	2 m/s
• Water Vapor Error > 7 mm	• Water Vapor Error < 2 mm	2 mm
• Cloud Water Algo Failed	• Cloud Water Error < 0.1 mm	0.1 mm
• Sea Ice Algo Failed	• Sea Ice Conc. Error < 10%	12%
• Rain Rate Error > 10 mm/Hr	• Rain Rate Error < 2 mm/Hr	5 mm/Hr
• Snow Water Algo Failed	• Snow Water EQ Error < 2 cm	3 cm
• Soil Moisture Algo Failed	• Soil Moisture API Error < 2 mm	NONE
• Land Temperature Error > 7 C	• Land Temperature Error < 3 C	NONE

Subsequent Cal/Vals: F10-F14

- Reduced Effort Due to Successful First Cal/Val Program
- Continuous Inter-Sensor Calibration for Continuity of EDRS
- Added Joint NRL/FNMOC Early Orbit Evaluation at FNMOC

SSM/I F8 Geolocation Results



WindSat Cal/Val Derived Requirements

Post-Launch

Pre-Launch

- T/V Calibration
  - Accuracy
  - NEDT
  - Stability
  - Algorithm
- Antenna Range
  - Beam Parameters
  - Polarization Purity
  - Feedhorn Spillover
  - Antenna Pattern Correction Algorithm
  - Ground Processing Software
    - SDR/EDR Products
    - Archive

Sensor Calibration

- Radiometer Stability
- Geolocation Accuracy
- Imaging Uniformity
- Radiometer Accuracy
  - A/C Underflights
  - Ground-Based Polarimetric Calibration
  - SSM/I
  - Model

EDR Validation

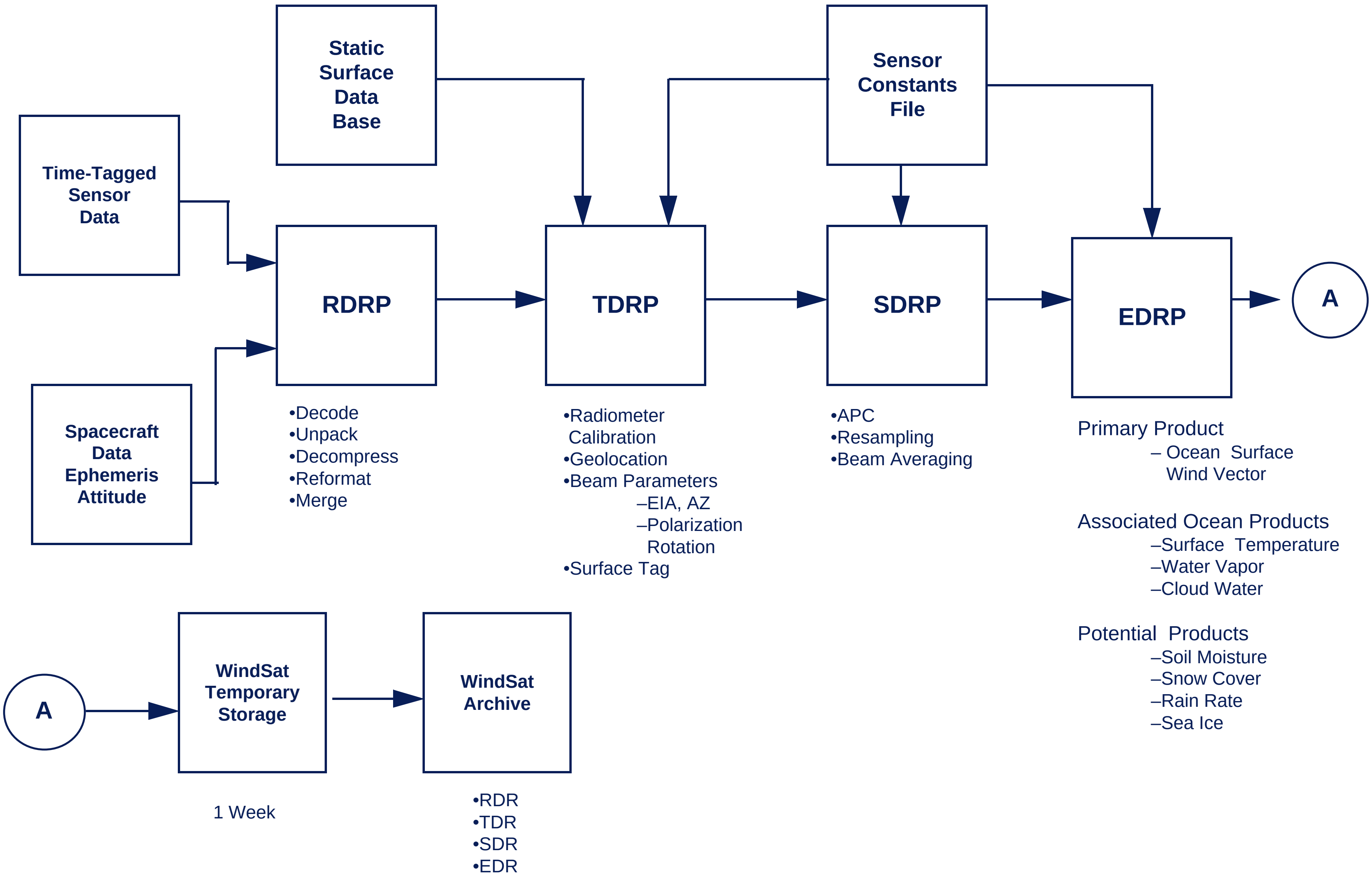
Primary

- Ocean Surface Wind Vector
  - Buoy/Ship OBS
  - SSM/I
  - NWP Fields
  - Active Sensors

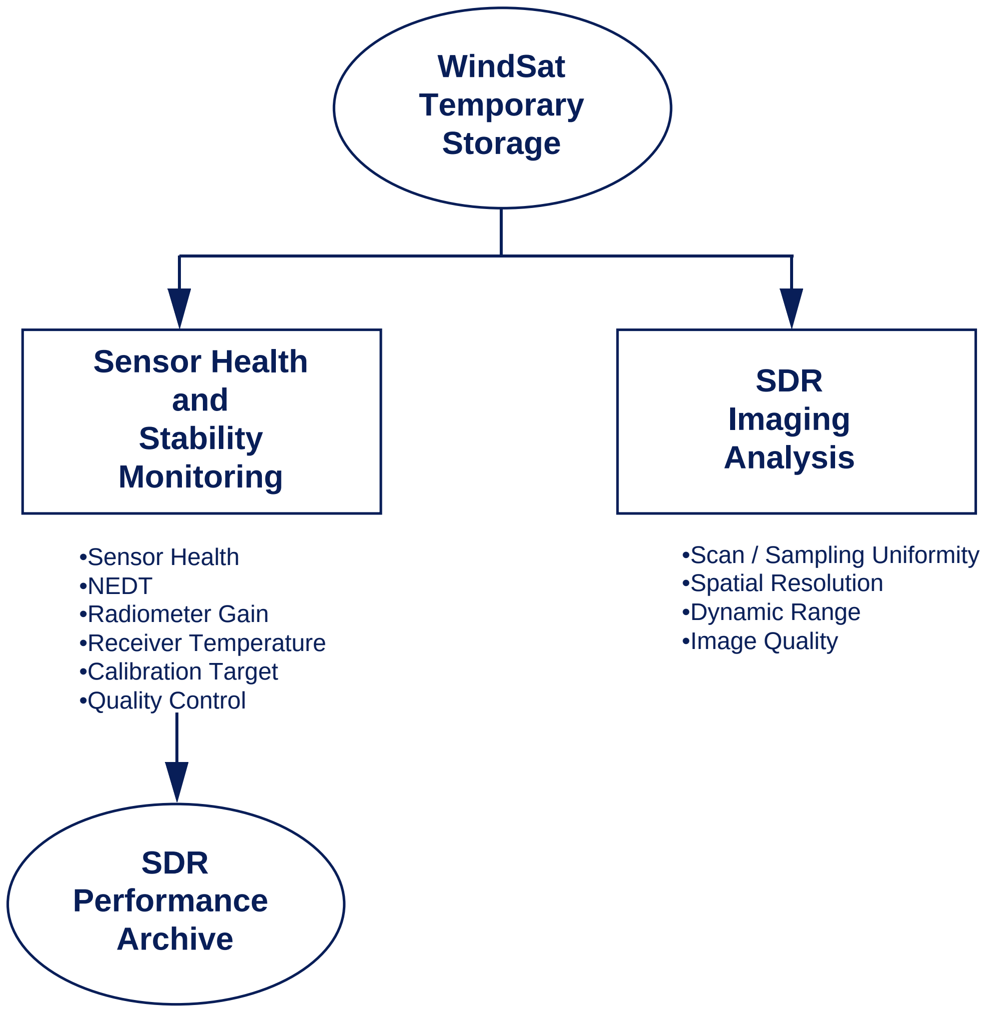
Associated

- Surface Temperature
  - Buoy/Ship OBS
  - SSM/I
  - AVHRR
- Water Vapor Mass
  - RAOBS
  - SSM/I
- Cloud Water
  - SSM/I

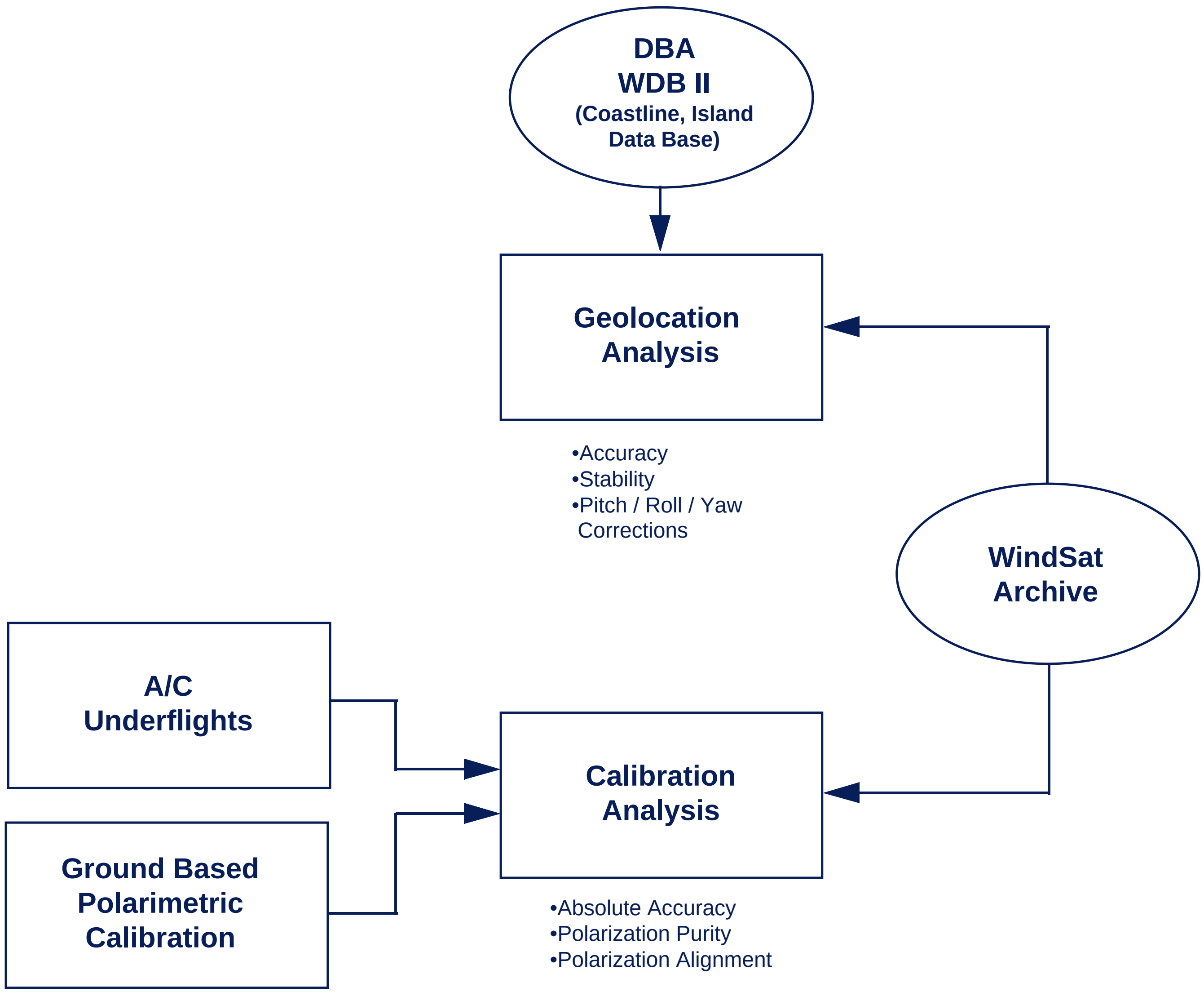
WindSat Ground Processing Concept



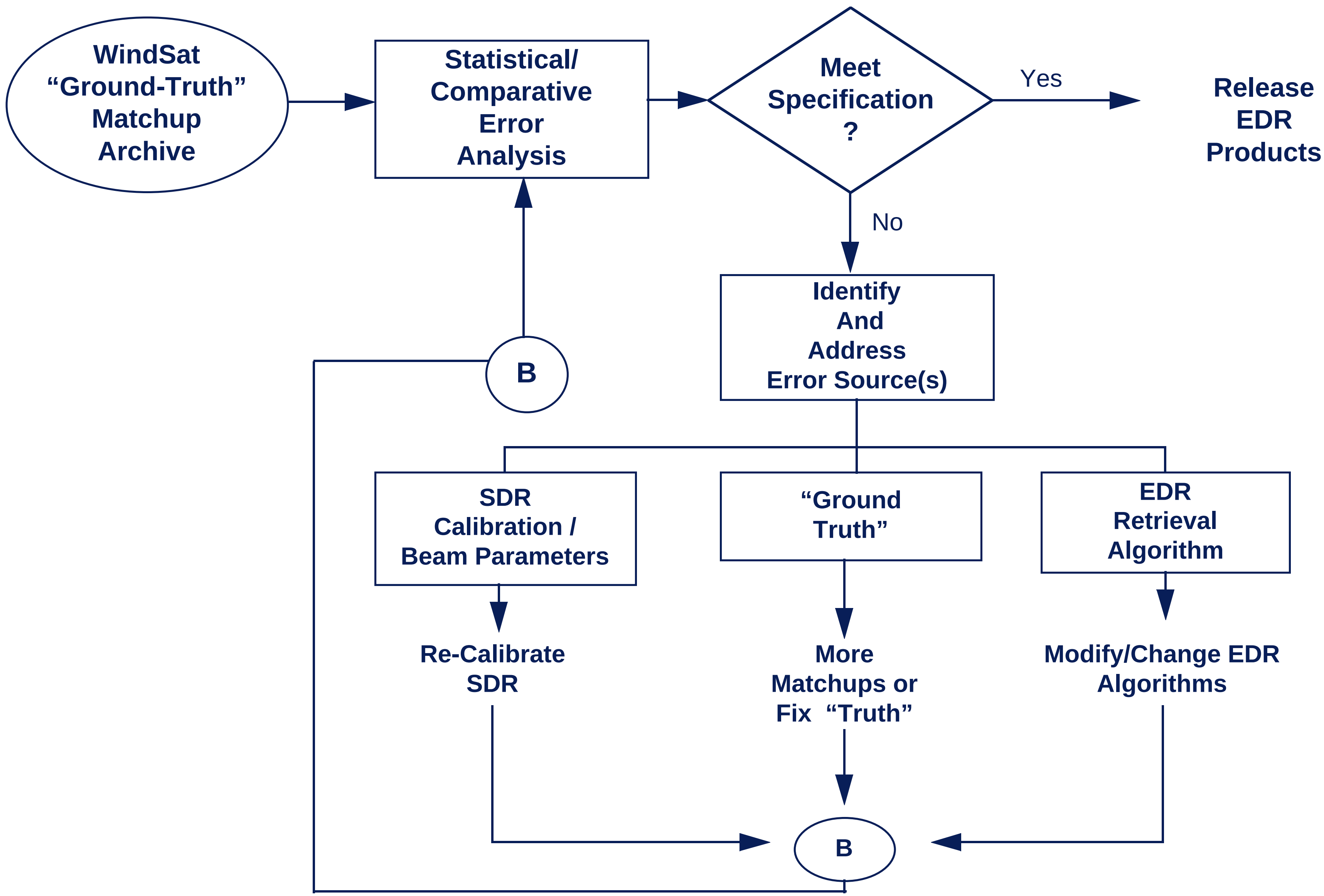
WindSat Sensor Calibration Concept (1 of 2)



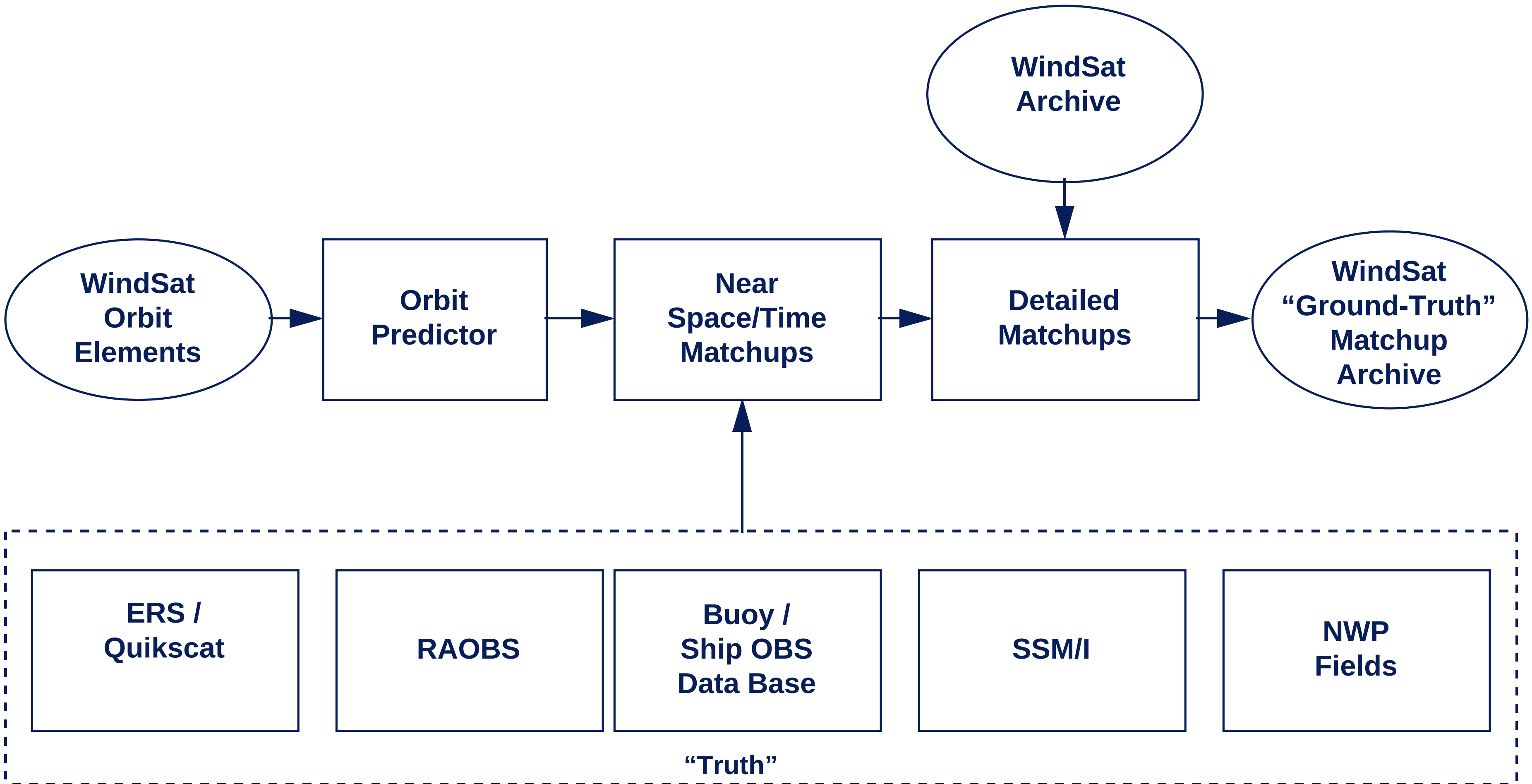
WindSat Sensor Calibration Concept (2 of 2)



WindSat EDR Validation Concept (1 of 2)



WindSat EDR Validation Concept (2 of 2)



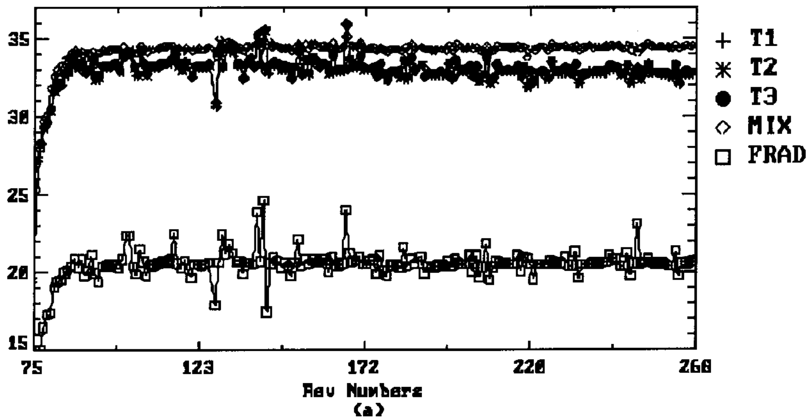
WindSat Cal/Val Requirements Summary

Sensor Calibration	Source
Health / Stability	On-Orbit Calibration Data
NEDT	On-Orbit Calibration Data
Absolute Accuracy	A/C Underflight
Polarization Purity / Alignment	Ground-Based Polarimetric Source
Horizontal Resolution	Image Analysis
Beam Coincidence	Image Analysis
Geolocation Accuracy	DMA WDBII (Coast-Line / Islands)
EDR Validation	**Source**
Ocean Surface Wind Vector	Coincident Buoy/Ship OBS; Active Sensors; NWP Fields
Sea Surface Temperature	Coincident Buoy / Ship OBS; AVHRR
Water Vapor	Coincident RAOBS; SSM/I
Cloud Water	Coincident SSM/I

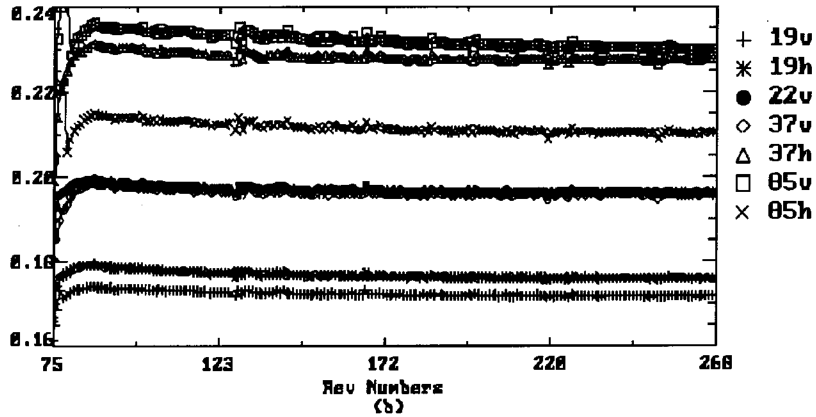
Backup

SSM/I F-14 Early Orbit Radiometer Stability

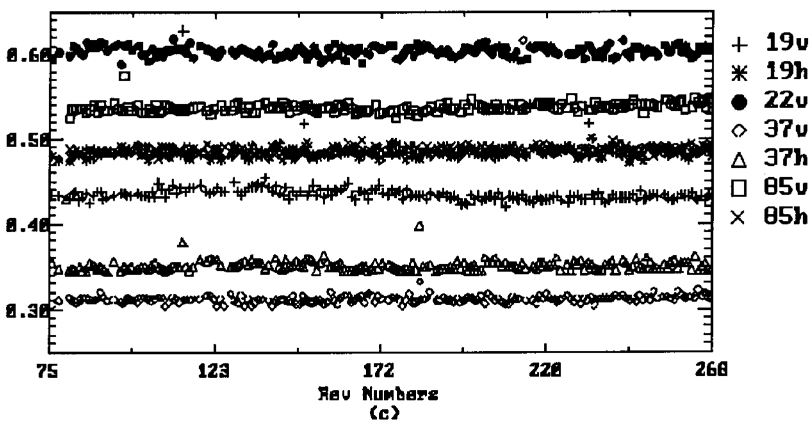
Temperature



Radiometer Gain

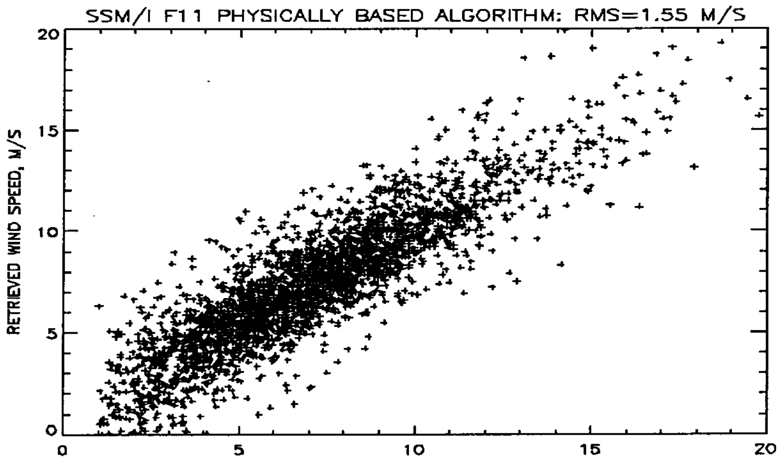


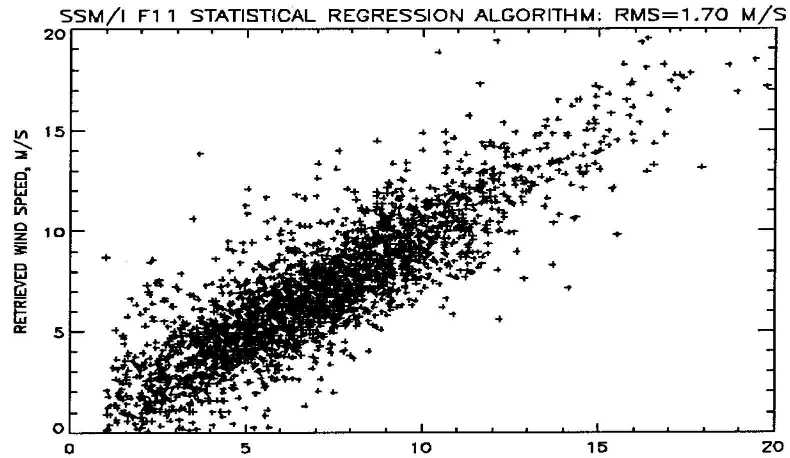
NEDT

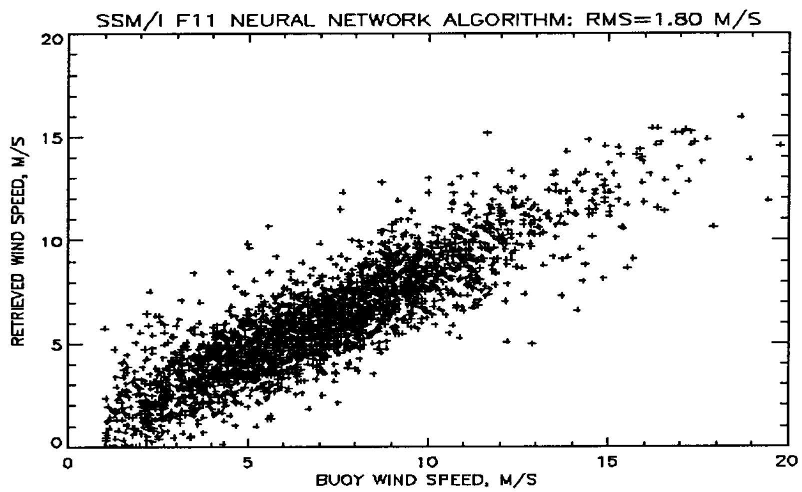


f-14_early_orbit.tif

SSM/I F-11 Ocean Wind Speed Performance Comparisons







algorithm.tif

Technology Transfer

P. Gaiser

WindSat Technology Transition

- WindSat Is a Risk Reduction Effort for the NPOESS CMIS System
- Technology to be Transferred Following Launch and During Development
- Post Launch
  - WindSat On-Orbit Data
  - Algorithms Used for Retrieving Wind Vector from WindSat
  - Data Compression Algorithms (If Needed by WindSat)
- Developmental
  - WindSat System Design
    - Receiver Design, Feed Horn Layout
  - WindSat Ground Test Results
    - Antenna Characterization Techniques, Detector Testing
  - Science and Technology Study Results (e.g. Polarimeter Antenna Performance Model)
  - Lessons Learned During WindSat Development

Present Top-Level Spacecraft Interface

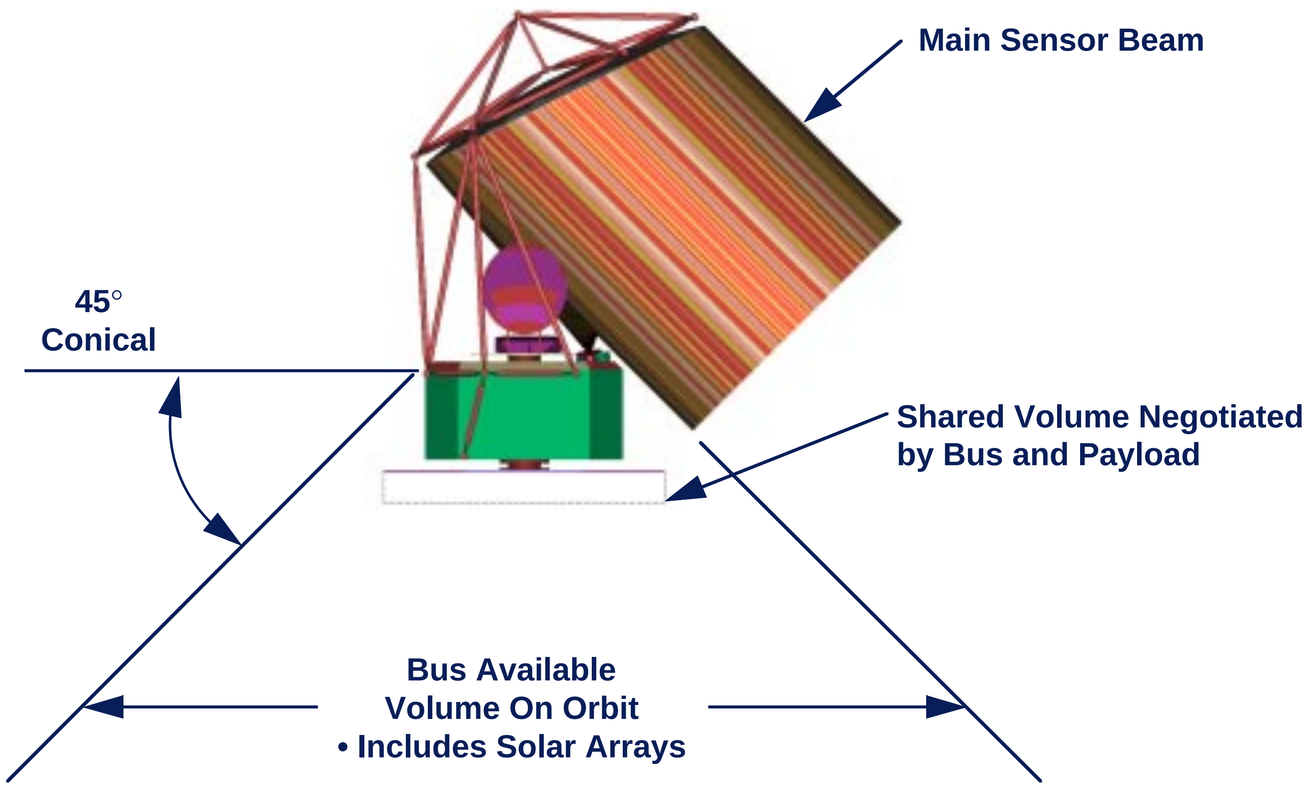
Spencer

Spacecraft Interface

- Structural Interface at WindSat Interface Deck
  - No Mechanisms Across Interface
- Thermal Interface
  - 0°C to 40°C at Interface
    - Applies to WindSat and Bus Side of Interface
  - No Requirement Heat Transfer Across Interface As Long As Both Sides Stay Within Required Temperature Range
  - Radiative Heat Exchange Requirements (TBD)
  - Integrated Thermal Model
- Reaction Control Subsystem
  - Driven by Orbit Circularity Requirements. Pending Future Analysis
  - Provide TBD Delta V
    - Corrects TBD Worst Case Orbit Insertion Error
      - ± 0.1° Inclination
      - ± 24 Nm Perigee
      - ± 10 Nm Apogee
    - Provides 3 Years Orbit Maintenance With TBD % Margin

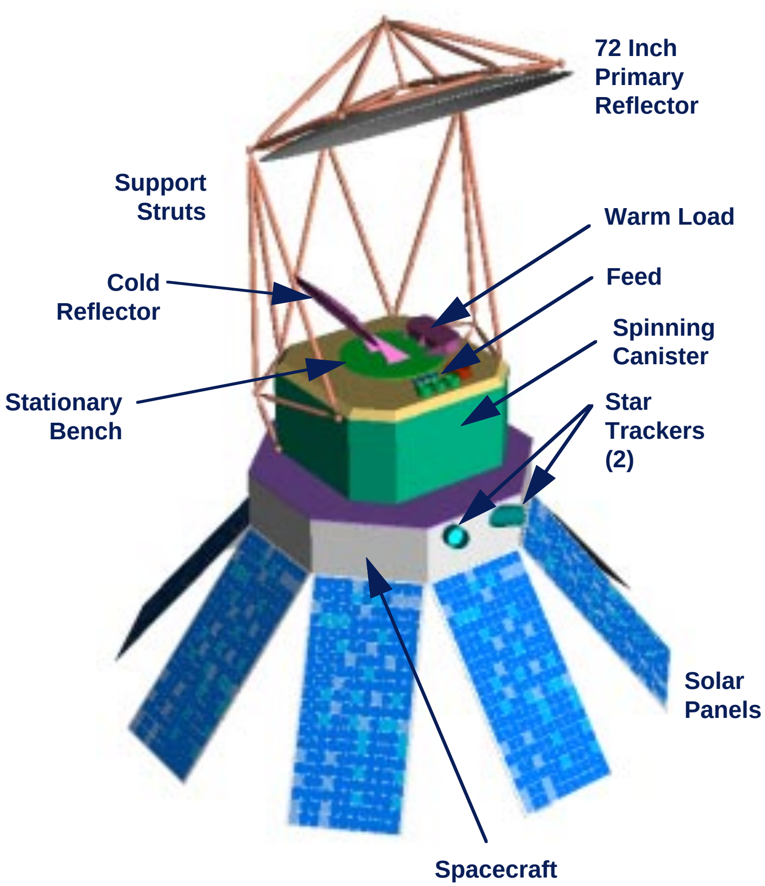
Bus On Orbit Envelope

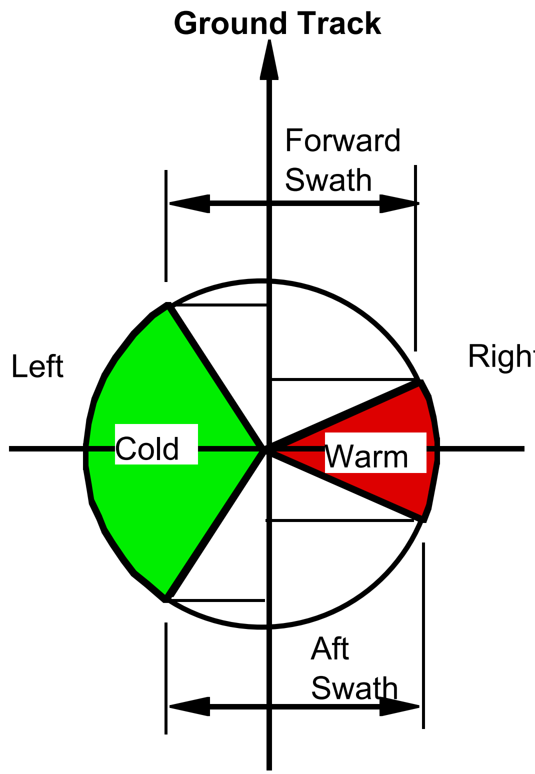
- **Bus Hardware May Not Be in Sensor Main Beam**



Subsystem Summary Level Budgets

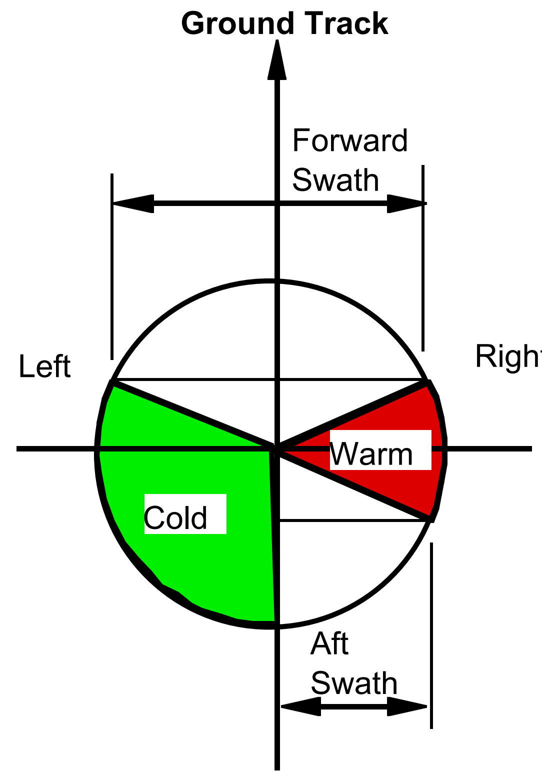
- **Example Subsystem Swath Allocation Among Reflector, Warm, and Cold Load**





Symmetyrical Cal Case

- **Forward Swath 913 Km**
- **Aft Swath 913 Km**



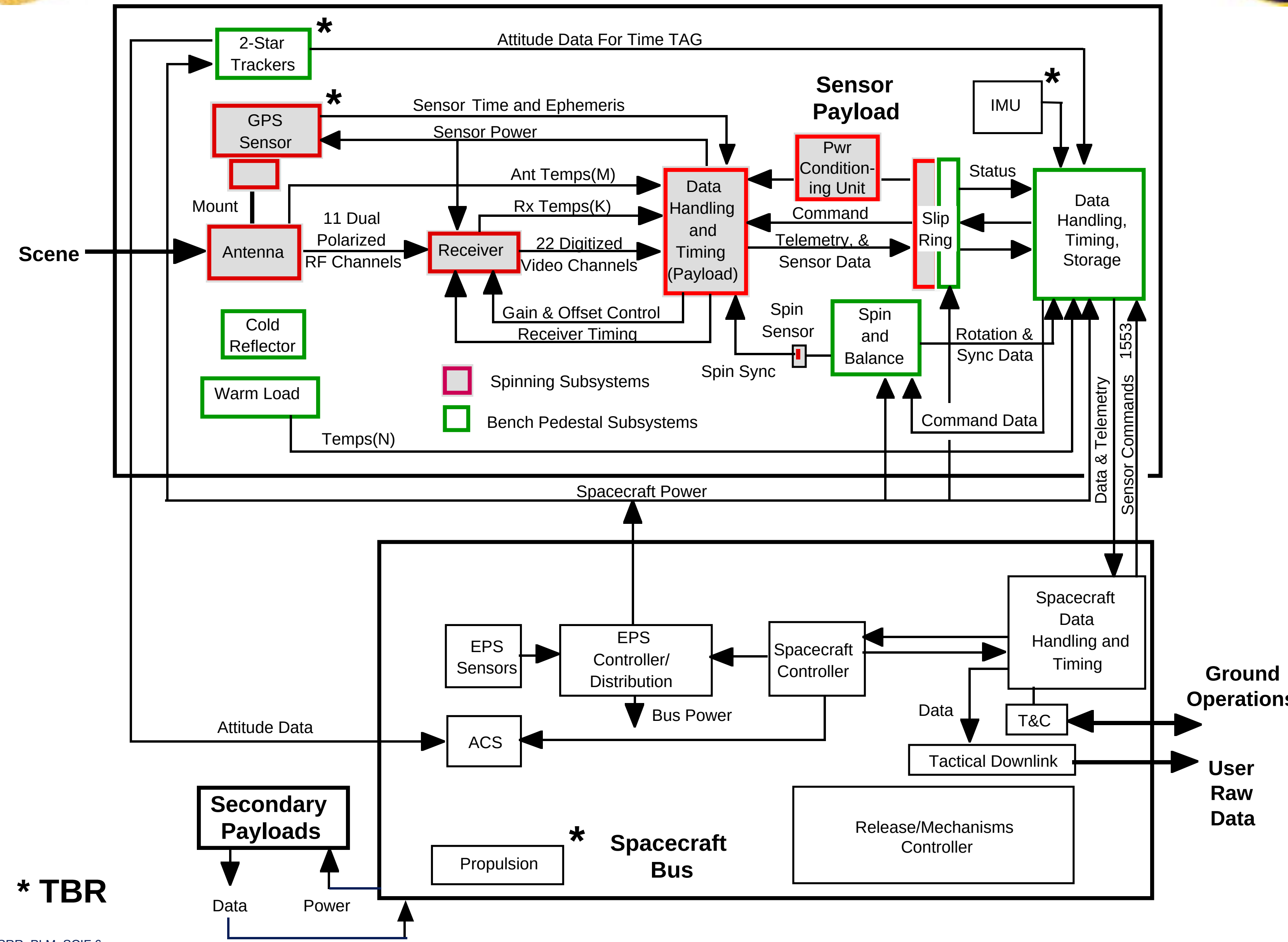
Assymetrical Cal case

- **Forward Swath 1053 Km**
- **Aft Swath 769 Km**

Payload Electrical Interfaces

- **Power: 30 $\pm$ 6 VDC, 659 Watts**
- **Bidirectional 1553 Data Bus:**
  - **ACS Data**
  - **Ephemeris**
  - **Uplinked and Time Phased Commands**
- **UTC Time Reference: 10 μ Sec Precision**

Subsystem Interfaces



* TBR

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